INTRODUCTION TO HEAT

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INTRODUCTION TO HEAT

Otto v. Guericke demonstrating the pressure of the air at Magdeburg, 1654

(From an engraving in the British Museum)

[*Intro.: Heat*
Mills & Boon Ltd.]

INTRODUCTION TO HEAT

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WITH 106 DIAGRAMS AND ANSWERS TO THE PROBLEMS

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INTRODUCTION

This book is designed for use both in the laboratory and as a textbook, chiefly for beginners, though a considerable amount of the work can be postponed most conveniently to a later stage in the boys' education.

The main idea underlying it is that boys are gifted with a large amount of curiosity, and that when they once realise that there is something behind many of the phenomena of everyday life they are prepared to take a good deal of trouble to satisfy their inquisitive instincts.

For this reason appeal is constantly made to the ordinary experiences of a boy, and experiments designed to elucidate these experiences are suggested. At the same time the boy is not made to think that he knows everything; it is hoped, rather, that he may be left in the frame of mind of Oliver Twist—asking for more.

The sections and paragraphs suggested for later reading have been asterisked.

The working of numerous problems and examples is essential to the proper progress of the student.

A. R. L.
G. W. T.

Newcastle-upon-Tyne,
May 1915.

CONTENTS

SECTION I

CONDUCTION AND CONVECTION

SECTION II

THE BAROMETER AND THERMOMETER

SECTION III

EXPANSION

SECTION IV

EVAPORATION AND CONDENSATION

SECTION V

ATMOSPHERIC MOISTURE

SECTION VI

FUSION AND SOLIDIFICATION

SECTION VII

SPECIFIC HEAT

SECTION VIII

RADIANT HEAT

SECTION IX

HEAT AND WORK

INTRODUCTION TO HEAT

SECTION I

CONDUCTION AND CONVECTION

1. THE IMPORTANCE OF HEAT.—Heat, and its opposite, cold, influence the lives of men to such a degree that it would be almost impossible to conceive circumstances in which men would be independent of them. Heat favours growth both in animals and plants, whilst cold retards it. This is true only within limits, for excessive heat not only retards growth, but destroys life itself, and the coldest regions on earth seem to be preferred by some creatures.

It is a common saying that "fire is a good servant but a bad master." This means that sources of heat should be understood. We should know what its effects are upon bodies, and how it may be controlled and regulated.

While man is able to live in all parts of the earth, no matter how hot or how cold it may be, yet life is more vigorous in certain temperate parts than in others. The inhabitants of both hot and cold countries are not so energetic nor so capable as those of temperate climes. The heat we feel is partly derived from the sun and in part is produced within us. In this country every endeavour is made during the winter to retain as much of our own heat as possible by the wearing of clothes.

2. *Why do clothes keep us warm?*—Are the clothes themselves warm? Do they supply us with any heat? What do you think would be the result of the following experiment?

Take two similar vessels filled to the same height with nearly boiling water. Let one vessel be wrapped in cloth, *i.e.* put a cloth "jacket" on it. Allow them to stand for fifteen minutes. Would there be any difference between them? What instrument would you use to see whether one vessel of water is hotter than the other?

Discuss this experiment, and if you determine to actually do it so as to find out the result, be careful to give a good description of it in your notebook, somewhat in this style—

EXPERIMENT NO. 1. (Date.)

To find the effect of placing a cloth jacket over a vessel of hot water.

Two exactly similar glass beakers were filled with boiling water. One beaker had been previously wrapped round with cloth. After waiting for fifteen minutes the fingers were placed in each, in order to determine which was the hotter. It was found that the jacketed vessel was decidedly hotter than the unjacketed one.

This shows that the cloth jacket had prevented the vessel from losing heat quickly.

We say that cloth is a bad conductor of heat.

Heat is said to be conducted away from a body when it is transferred from particle to particle of the conductor without the particles themselves being apparently moved.

3. GOOD AND BAD CONDUCTORS.—Some substances are good conductors of heat, others are bad ones. Can you suggest any way in which you could determine whether a given substance is a good or bad conductor?

Try your method on paper, cloth, glass, metal and anything else you come across. In your notes say—

1. What you are trying to find out.
2. What you do in order to find it out.
3. What you observe.
4. What you learn.

If you cannot at present think of any method defer it until you have finished the chapter and then try again. Make notes as the following experiment is performed.

To show that mercury (a metal) is a better conductor than water (a non-metal).

Bend a piece of thick wire into the form A, and after making it as hot as possible, place the prongs into two test tubes containing equal volumes of mercury and water. Allow the prongs just to enter the liquid. From the bottom of the test tubes two shots are suspended by means of wax. Note and explain what happens.

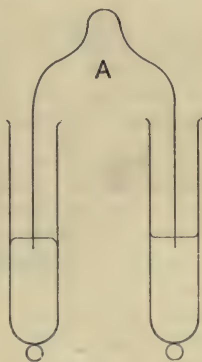


FIG. 1.

To show that one metal is a better conductor of heat than another.

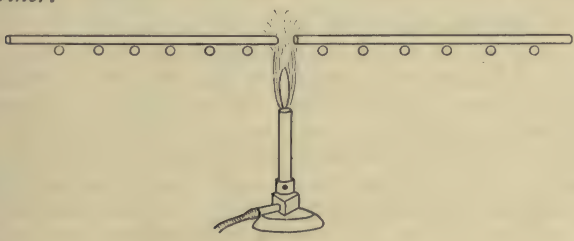


FIG. 2.

Carry out the experiment suggested by the diagram. Note very carefully the conditions necessary to make it a success.

Note that in this sketch, as in all following ones, the necessary supports are omitted. The student should devise suitable ones for himself.

You will note that **as a general rule metals are better conductors than non-metals.** How can you distinguish a metal from a non-metal? Classify the following into metals and non-metals: Paper, glass, iron, ivory, copper, bronze, wood, silver, cloth, wool, cotton, aluminium, gold, clay, sand.

Ask yourself the question about each: "Is this a good or bad conductor; what is my reason for giving this answer?" Make a list of the good conductors and see whether the statement at the head of the previous paragraph is true.

4. THE USES OF GOOD CONDUCTORS.—In ordinary everyday life good conductors are used to carry artificial heat, that is, heat produced by fires, etc., to wherever it has to be utilised. Stoves are made of iron, which is a good conductor, so that the heat of the fire may be carried to the oven and boiler or to the top where it is used for cooking. The cooking vessels are made of metal—iron, tin, aluminium, silver or brass—so that the heat of the fire is quickly carried to the food that is being cooked. When large rooms are heated by hot water or steam pipes, these are made of iron, and the radiators for distributing the heat are also of iron.

5. EXPERIMENTS WITH GOOD CONDUCTORS.—In the following experiments we are going to use a bunsen burner or a candle as a source of heat, and it is necessary to understand a little about the lighting of a candle or bunsen. Substances such as gas and the vapour of oil or melted fat will burn only when they are hotter than a certain temperature called their "temperature of ignition." When the match has to be lighted it is rubbed on the side of the box until the heat produced by rubbing raises it above its temperature of ignition, and it then bursts into flame. The lighted match is held near the gas coming from the bunsen. This raises the temperature of the gas above its temperature of

ignition and the gas catches alight. When a fire is lighted the match is first struck and applied to the paper. This, when it gets hotter than its temperature of ignition, ignites. The heat from the burning paper raises the temperature of the wood above its ignition temperature, and that also bursts into flame. The wood then sets fire to the coal in the same way. The heat produced by the match alone would not have been sufficient to do this. In a similar way describe how a candle is lighted.

If anything happens so that the temperature of a burning body is reduced below its temperature of ignition, then it will go out.

Now try these experiments—

Obtain a block of wood about $6'' \times 3'' \times 2''$, and into one face of it screw half a dozen *thick* brass screws until their heads are flush with the wood. Now cover the whole with paper and place it in the bunsen flame sufficiently long to scorch the paper but not long enough to set it alight. What do you notice about the paper? How is it that the scorching is not equal all over the paper?

Coil a piece of *thick* copper wire into a spiral just wide enough to go over a candle flame. Allow the end of the wire to project into the centre of the spiral. Place it over the flame of a candle, and note and explain what happens. Suppose it was argued that the flame went out for want of air, how would you arrange the experiment so as to show that this is not the case? Repeat the experiment with the coil first made red-hot in the bunsen. What is now the result? How do you explain it?

Hold a piece of copper gauze above a bunsen flame and gradually bring it down into the flame. Describe and explain the result.

Hold the piece of gauze just above an unlighted bunsen and then light the gas above the gauze. Explain what happens.

In the above experiments note what happens when the gauze gets red-hot and explain.

* 6. THE DAVY LAMP.—This property possessed by wire gauze of preventing a flame from passing through it, has been utilised in the construction of miners' safety

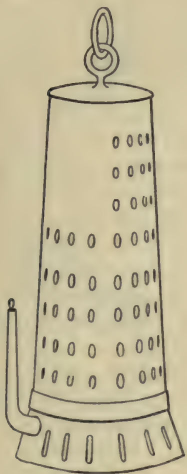
lamps. It was at the beginning of the nineteenth century that a succession of calamities in the collieries of Northumberland impelled George Stephenson to strive to find a remedy for the evil of explosions which imperilled the lives of miners. He made experiments to find out how fast explosions travelled up metal tubes of different diameters, and discovered that the smaller the diameter was the slower travelled the explosion. Having satisfied himself on this point he constructed a lamp with a metal cover containing a large number of small holes. The rate at which an explosion went outwards from the flame would then be less than the rate at which the air of the mine went into the lamp, and therefore the flame would never travel to the outside. George Stephenson fearlessly tried his lamp in the most dangerous parts of mines, and found it perfectly safe. Although he was not a scientist he had gained a scientific victory.

Can you give an explanation of Stephenson's observation that a flame travelled more slowly up a narrow metal tube than up a wide one?

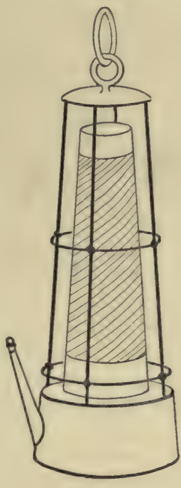
While this humble overseer of colliery machinery was making his experiments and endeavouring to improve his invention, one of the greatest philosophers of the time was employing his vast knowledge in designing a similar contrivance. Sir Humphrey Davy's lamp was constructed on exactly the same principle as Stephenson's, although neither knew of the other's work. Instead of a metal cover with a large number of holes drilled in it, Davy made the holes as numerous as possible by using metal gauze as a cover for his lamp.

The first "Geordie" lamp was proved as to its safety on October 21, 1815. Fourteen days after—on the 4th of November—Stephenson's second lamp was similarly tested and found to be not only as safe as the first, but also of greater illuminating power. On the 9th of November the first "Davy" lamp was shown in London, therefore in point of priority history must give the place of honour to the "Geordie."

In your experiments with wire gauze you will have noticed that the flame gets through when the wires get unduly heated. By exposing a lighted safety lamp to a strong air draught the flame may be driven against the gauze long enough to heat the metal and then the flame may get through. Miners have to guard against this. Occasionally during "shot-firing" the concussion to the air has been known to blow the fire of a safety lamp bodily through the gauze.



"Geordie"



"Davy"

FIG. 3.

By the behaviour of the flame of a Davy lamp when placed in an atmosphere containing "fire damp" one can tell approximately the percentage present. The size of the flame increases with the amount of fire damp.

7. THE USES OF BAD CONDUCTORS.—When we first began to talk about good and bad conductors we noticed

that cloth was a bad conductor, *i. e.* that it opposed the passage of heat through it. Hence clothes are used to retain bodily heat. Exercise produces this heat and the clothes more or less prevent it from escaping. Of course the clothes cannot keep you warm if the body is not producing heat.

When buildings have to be warmed by hot water or steam it is essential that heat should not be wasted in underground passages on the way to the rooms, so the pipes are here covered with felt, or, better, with asbestos, which is a worse conductor than felt or cloth.

Air is a very bad conductor if it can be kept still. Of course, when moving it carries the heat away quite easily. In the winter eiderdown quilts are used because the air within prevents the passage of heat through them, and they feel quite warm and cosy. Your mother no doubt uses a tea cosy to keep the teapot from getting cold—how does it do it? In private hospitals and some houses double windows, one within the other, are used to keep the warmth of the fire within the room. So also in Canada and cold countries, the walls are double with an air layer between. This keeps the rooms warm in winter and cool in summer, but it also serves another purpose—what is it?

Certain foods in order to be cooked properly must be kept in hot but not boiling water, for a considerable time. This is best managed by employing a "fireless cooker" as the Americans call it. It consists of two wooden boxes one within the other, but separated by a space packed with glass wool or other substance which prevents the circulation of the air. The things to be cooked are heated in a metal vessel, placed in the box and covered up. The heat does not escape and is sufficient to finish the cooking.

In a similar way refrigerators are constructed to keep out the warmth. They consist of double vessels with charcoal packed between them. The article to be cooled is placed within the inner vessel and the ice is put on top.

Air is a very bad conductor; a vacuum, or space

empty of air, is a worse conductor. Thermos flasks consist of a metal case enclosing two glass flasks one within the other, and so connected that the air can be pumped out from between them.

This vacuum prevents the passage of heat through it and the flask will keep its contents hot for many hours. You will have noticed too, perhaps, that the glass flasks are silvered. The reasons for this will be seen later.

Brick and wood are bad conductors and are therefore excellent materials for building houses where it is necessary to keep the warmth in during winter and out during the summer.


FIG. 4.

Of the two, brick is the worse conductor, which is convenient since it is used for building fireplaces, chimneys and furnaces, where the heat to be retained is very great. Is there any other reason, though, for using brick?

Glass is also a bad conductor. Note the use of glass wool above. Note the use of glass for windows and fire-screens. We shall, however, have to return to the use of glass later on, for it is strange that while it is used in fire-screens to keep the heat of the fire away from a person near to it, yet glass houses exposed to the sun's rays become excessively hot inside.

ADDITIONAL EXPERIMENTS.

1. How would you determine the rate at which heat is transmitted through an iron rod? Construct a graph to illustrate.

*2. Obtain some strips of metal, about $\frac{1}{2}'' \times 10'' \times \frac{1}{16}''$. Heat the ends of these in a bunsen flame and when hot place upon them a piece of "sensitive paper" (§ 151) with its edge at the same distance from the heated portion of each. Note and explain the result.

Questions and Problems—I.

1. What advantages are there in the use of thatched roofs?

2. Many months after the eruption of Vesuvius the bottom of the cracks in the lava were quite hot, though the surface was cold. How do you account for this?

3. In the Arctic regions all metal articles which have to be handled are covered with flannel; why is this?

4. Some baked potatoes are placed in a flannel bag; pieces of ice are placed in another similar bag. What happens in each case? Give your reasons.

5. If milk is boiling over a fire a metal spoon placed in the vessel will stop the boiling for a short time but not for long. How do you account for this? Would a wooden spoon do as well?

6. Porridge in a plate cools much more quickly near the edge of the plate than it does in the middle of the plate. Give reasons for this.

8. Another Method of Transmitting Heat.—We have up to now been considering the conduction of heat. When heat is conducted along a body there is apparently no motion in the conducting body. Even when speaking of the poor conducting power of air we had to presuppose that the air was kept still.

Fig. 5.

Let us now see what would happen if the heated air is permitted to move.

Cut out a piece of stout paper as in the figure; pass a pin through the central point and hold it up so that it looks like a spirally wound snake hanging by its tail from a pin head. Hold it over a bunsen flame but not close enough for it to catch alight. What happens? Try and

explain the cause of the movement. When air is heated, what does it do? How would you show the same truth in another way?

The heat from the bunsen has passed to the air around and above it; this air has moved and carried the heat with it. Place your hands on either side of the bunsen; do you feel it much hotter? Now place one hand above the bunsen; what do you feel? If the hot air is moving upwards then, in those homes where gas is used for lighting purposes, the air near the ceiling will get very hot at nighttime. Perhaps you can think of some way of testing whether this is so.

Air is a bad conductor of heat and yet it is able to transmit heat rapidly from one place to another. It is able to do this because it moves upwards carrying the heat along with it.

9. Convection Currents in Water.—Is air the only substance which will carry heat in this way? This is the question we must ask ourselves and try to answer.

Fill as large a flask as you can obtain with water up to the neck. When it has stood still long enough for the water to be practically at rest, drop in a lump of some colouring substance, and as it dissolves heat the flask at A (fig. 6). The streams of colour will show you which way the water is moving. Describe this motion and explain it as far as you can.

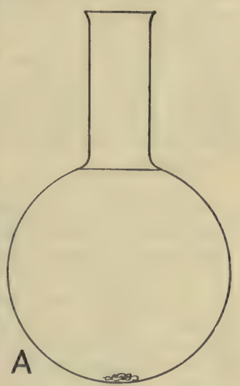


Fig. 6.

Is it quite certain, however, that the movement of the water is due to its being heated? Try this experiment.

Bend a piece of glass tubing as in figure. Cut off the ends if they overlap, so that a T-piece will fit in between.

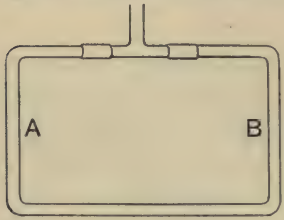


FIG. 7.

Use short pieces of rubber for joining the T-piece on. Fill the tube quite full of water (it is not easy to do so if the tubing is narrow), place the colouring substance at C and heat gently at A. Note what happens. Now heat at B instead and again note what happens. What deduction do you draw?

The stream caused by the hot water rising and the cold water following is called a convection current. **Heat is carried in convection currents by the movement of the particles themselves from one place to another.** Convection currents can be formed in all sorts of fluids, but those in air and water are the ones most often met with.

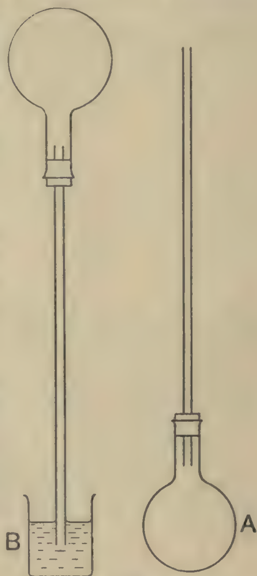


FIG. 8.

10. *Why does the air or water rise when heated?*—Try and follow the argument of this very carefully. It is divided up into five parts.

(1) A flask is fitted, as in diagram A, with a tightly fitting cork and glass tube, and after being slightly warmed, is inverted in a vessel of coloured water as in B. Cool the flask; what happens? What happens when it is warmed again? State the result of this experiment.

(2) Many years ago, about 300 B.C., the wiser of the philosophers, among whom was Aristotle, believed that heavy substances fell because they possessed "gravity," and that light sub-

stances rose because they possessed "levity." According to them hot air possesses "levity," and therefore rises above the cold air. Even nowadays people will say that the hot air rises because there is a certain lightness about it that makes it do so. We can, however, show that this is not so, that all things possess gravity or weight, and that the earth pulls things down with a force proportional to the weight of the body. Still, Aristotle's idea of "levity" sounds sensible and we had better prove that the air can be weighed and therefore possesses gravity.

Fit up a flask with a good air-tight cork with tube and tap. Put some water into the flask, open the tap and boil the water till only a little is left. Then close the tap and weigh the flask. Now open the tap and weigh the flask again. Explain the cause of any difference in the two weighings. When writing your notes state carefully what the flask contained and how the contents changed as the experiment progressed.

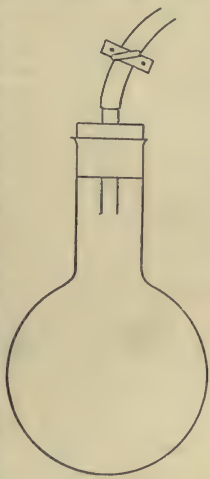


FIG. 9.

When weights have to be taken during an experiment enter them into your notebook, after having described the experiment, as follows—

Results.

Weight of flask, water and condensed steam . .	=	gm.
Weight of flask, water, condensed steam and air .	=	gm.
Difference . .	=	gm.

The difference of . . . grams must have been the weight of the air that entered the flask on opening the tap.

Can you suggest any other way in which we can prove the same truth, that air has weight?

(3) The next step in the proof is to show that warm air is lighter, bulk for bulk, than cold air. Imagine that a flask filled with air is heated. This will not change the weight of the flask, but it will cause the air inside it to expand and overflow. This means that a flask full of hot air is not as heavy as a flask full of cold air. Therefore 1 cubic inch of hot air is not as heavy as 1 cubic inch of cold air, nor is 1 c.c. of hot air as heavy as 1 c.c. of cold air. Now the weight of unit volume (that is 1 c.c. or 1 cubic inch, etc.) of any body is called its density. Therefore we say that the density of cold air is greater than that of warm air.

(4) Remember that we have proved so far—

(1) That air expands when heated.
(2) That air has weight.
(3) That cold air is denser than warm air, *i.e.* that, bulk for bulk, cold air is heavier than warm air.

We have now to see how liquids of different densities will arrange themselves if mixed.

Measure out into separate vessels equal quantities of mercury, water and turpentine. Weigh each of them and determine the density of each, that is the weight of 1 c.c. of each. Now mix them together in a long tube. How do they arrange themselves? Write down the result of this experiment.

If you have time try some other experiments of your own devising, or the following ones, in order to prove the same thing.

(*a*) Attempt to pour hot coloured water so that it will float on the top of cold uncoloured water.
(*b*) Attempt the pouring of the cold water on top of the hot water. Explain your success or failure as the case may be.
(*c*) Into a U-tube put some coloured turpentine and then pour water into one limb. Which liquid occupies the bend of the tube? Why? Which one rises highest up the tube? Why?

(5) Now the last step in the set of experiments is to show that cold air, being denser than hot air, goes to the bottom and forces the hot air up. It is in this way that convection currents are set up. It is not the hot air that rises and "draws" the cold air after it but that the cold air falls and pushes the hot air up. People often say concerning a fire that the chimney "draws" well. This is not quite the correct word to use, nor is it quite correct to talk about the "draught" caused by the fire. It is very difficult, though, to get rid of old ideas, no matter how wrong they may be. We shall, however, have to consider this subject more fully.

* 11. *Why do dense fluids sink to the bottom.*—In the experiments just finished we have only shown that the densest fluids sink to the bottom, we have not given any reason as to why they should do so. We must now try to understand why.

We have seen that all bodies possess gravity and that in consequence they are all pulled towards the centre of the earth. If we wish to prevent a body from falling to the ground, we must exert a force which will counteract the pull of the earth on the body. This force, we shall find, will be sufficient if applied at one particular point. Thus a dinner plate can be held up if we place the end of a pencil under its centre and press upwards. A stick can be balanced upon a knife edge if the latter be directly under the centre of the stick. Thus we can counteract the pull of gravity, *i. e.* the pull of the earth on a body, if we apply a single upward push at one particular point. This point is called the centre of gravity.

The centre of gravity of an irregular metal plate can easily be found by balancing it on the end of a pencil. The point at which it will balance will be the centre of gravity. Now if the plate be suspended from any point, it will be found that the centre of gravity is always directly below the point of suspension. The centre of gravity always takes up the lowest possible position when a body comes to rest. A pendulum, for instance, comes to a standstill when the bob is directly under the point of suspension.

If there are several bodies each will have its own centre of gravity. If they are joined together then the whole combination will have one centre of gravity, and this will be the one to take up its lowest possible position when the combination comes to rest.

Suppose now we have two liquids of different densities contained in cylindrical vessels A and B. The centre of gravity of each will be at the centre of each cylindrical mass of liquid. Now, assuming that they will not mix, let us place one above the other. There are only two possible arrangements, either C or D according as the

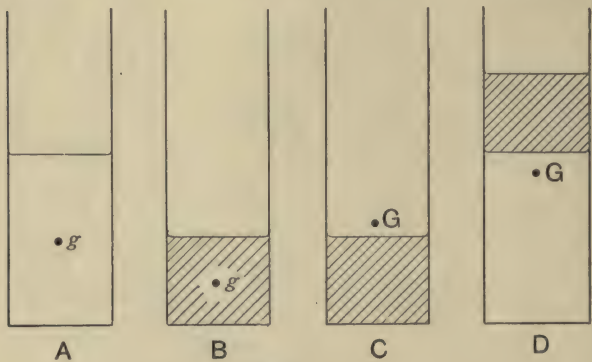


FIG. 10.

denser is below or above the lighter. If the liquid B is the denser of the two, then the centre of gravity of the two combined will not be halfway up the combined liquids, but nearer the centre of gravity of the liquid B. You will see on reference to the diagram that B must be at the bottom if the centre of gravity G has to be at its lowest point.

You will understand now why cold air sinks to the bottom and why cold water falls pushing the warmer water upwards.

Questions and Problems—II.

It will be well to make certain that you understand about the centre of gravity and its properties, therefore try and answer the following—

(1) A bottle standing on a table is slightly tipped to one side. Explain what happens. Suppose it was standing upside down, explain what would now happen if it were again tipped.

(2) A tumbling Jack is a toy man which will not lie on its side; how does it work?

(3) A toy sailing boat would not float upright until a piece of lead had been fastened to the keel. What difference did this make?

(4) How does a rocking-chair behave when tipped backwards?

(5) How would you find the centre of gravity of a brick?

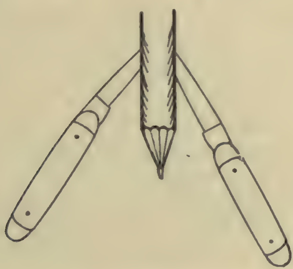


Fig. 11.

(6) A pencil cannot be easily balanced upright on the finger, but if two penknives be fastened to it as in the sketch it will easily balance. Explain this.

(7) Why are conical safety ink bottles safer than cylindrical ones?

(8) Why is it safer to sit down in a canoe than to stand up?

12. Convection Currents in Everyday Life.—We are living within the fluid air and using the fluid water and we are constantly having to use artificial heat either for cooking or warming. Hence it will be easily understood that convection currents are very common in the home and play an important part in it. Again, the presence of the sun as a source of heat will also make convection currents on a large scale of frequent occurrence on the earth.

The warming and ventilation of our homes are due to these currents, so also are the trade winds, monsoons, and land and sea breezes.

13. Convection Currents in the Home.—The chief convection currents in a house are those produced by fires. The air around the fire is heated and is pushed up the chimney by the inrush of cold air. The latter enters by any available inlet, chiefly by the door and window, and its passage across the floor can often be felt, producing cold feet and inducing older people to use hassocks. Such persons often suggest that the room is cold and that making the fire burn brighter and hotter will do away with the cold draught. Will it do this? If not, what will it do? Suggest some way of getting rid of the cold draught.

It will be noticed that factories which require a much hotter fire or furnace than is required in our homes always build a much higher chimney. This suggests that the bright burning of a fire depends upon the height of the chimney. Can you mention any other ways of making a fire burn more brightly? Explain each suggestion.

14. *To show how the height of a chimney affects the fire.*—Turn back to § 9 and again read over the experiment on convection currents in water. For simplicity's sake, we will first deal with these. Consider two columns of water, one A at 0° C., the other B at 50° C., each of them being 60 cm. high. Let these two columns be joined top and bottom so as to permit a convection

current to flow. On each sq. cm. at the bottom of column A there will be a column of 60 c.c. of water pressing. The weight of this column will be 60 grams, for each c.c. weighs 1 gm. On the bottom of the other column there will be a pressure of 60 c.c. of water, but since it is hot water, 1 c.c. will only weigh ·988 gm. Therefore the pressure on each sq. cm. at the bottom will be 60 × ·988 gm.

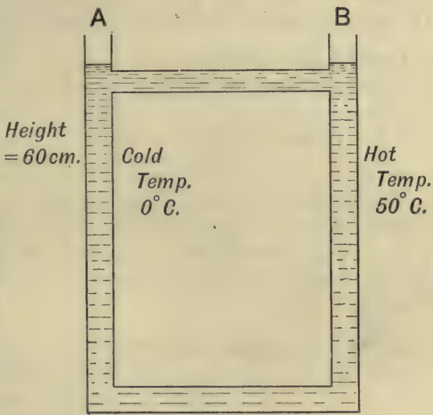


FIG. 12.

$$\begin{aligned} \text{Pressure in col. A} &= 60 \times 1 \text{ gm.} \\ \text{,, \quad ,, \quad B} &= 60 \times \cdot 988 \text{ gm.} \\ \hline \text{Difference of pressure} &= 60 \times \cdot 012 \text{ gm.} \\ &= \cdot 72 \text{ gm.} \end{aligned}$$

This extra pressure on the cold side will cause it to move downwards, the hot column being pushed upwards. A convection current will therefore be started, and the greater the difference of temperature and the greater the height of the columns, the greater will be the pressure causing the flow.

(*a*) Calculate what the pressure will be which causes the flow when the temperatures of the two columns are 0° C. and 90° C. and the height of the columns is 200 cm. It is given that 1 c.c. of water at 90° C. weighs ·9653 gm.

We can apply the same reasoning to chimneys. You will have noticed that the width of the columns does not come into the calculation, hence it will not bother

us when we note that the colder air outside the house has no definite width.

(*b*) Calculate the pressure which causes the flow of air up a chimney from the following—

Height of chimney	= 1000 cm.
Average temperature of outside air .	= 20° C.
" " flue . .	= 120° C.
1 c.c. of air at 20° C. weighs . .	·0012 gm.
1 c.c. " 120° C. " . .	·0009 gm.

The result will show clearly that the air inside the flue presses downwards much less than the air outside, and that the difference which causes the flow depends upon (1) the height of the chimney, (2) the temperature of the flue.

15. *To determine how much* 1 *c.c. of air expands when heated* 1° C.—In the previous problem the weight of the air at each temperature is given. These weights could, however, be easily found by means of this and the next result. That is the purpose of this experiment.

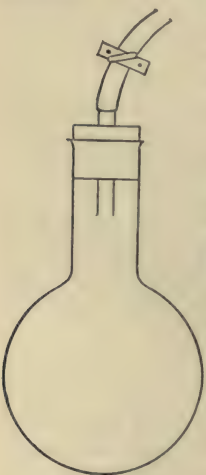


FIG. 13.

Thoroughly dry a flask and fit it with a cork through which passes a tube and tap.

Obtain two vessels which will hold the flask when covered by water, and into one of them place cold water and into the other put some hot water.

Place the flask with tap open into the hot bath and note its temperature. Close the tap, transfer the flask to the cold bath and open the tap under water so that no air can get in. Take the temperature of the cold bath.

Measure the water that has passed into the flask and measure also how much the whole flask will hold.

Let us suppose that the following are the results obtained—

Temperature of cold bath . .	$= 15°$ C.
Temperature of hot bath . .	$= 85°$ C.
Volume of flask	= 200 c.c.
Volume of water entering flask .	= 40 c.c.

At the end of the experiment the flask held 160 c.c. of air and 40 c.c. of water. If it is now inverted in water at 85°, the 160 c.c. of air would again expand and fill the flask. That is, 160 c.c. of air would expand 40 c.c. when heated from 15° C. to 85° C.

160 c.c. of air heated 70° C. expands 40 c.c.

1 c.c. ,, ,, ,, ,, $\frac{40}{160}$ c.c.

1 c.c. ,, ,, 1° C. ,, $\frac{40}{160} \times \frac{1}{70} = \frac{1}{280}$ c.c.

The result of this experiment shows that 1 c.c. of air heated 1° C. expands $\frac{1}{280}$ c.c. or ·00357 c.c.

Your answer may be somewhat different from this, indeed no two answers will probably be alike. Supposing a whole class did the experiment each separately and got different results, how would you find the most probably correct result?

An accurate and at the same time convenient result is $\frac{1}{273}$.

16. *To determine the weight of one litre of air.*

Using the same flask as in the last experiment, place a small quantity of water in it and boil rapidly, with the tap open, to drive out all the air. Close the tap, cool and dry the flask and weigh it. Open the tap to admit the air and weigh it again. What will the difference between the two weights represent? Find the volume of the flask; this will be the volume of the air it contained. The weight of 1000 c.c. of air can then be calculated.

If these weighings had been done at 0° C. you would have found out that 1000 c.c. of air would weigh 1·29 gm.

MATHEMATICAL EXERCISES—I.

1. A flask holding 237 c.c. of air is raised to 50° C. in a hot bath. It is then transferred to a cold bath at 15° C. and the tap opened; 27 c.c. of water entered. Calculate how much 1 c.c. of air expands when heated 1° C.

2. From the following results calculate the expansion of 1 c.c. of air when heated 1° C.—

Temperature of cold bath .	= 15° C.
Temperature of hot bath .	= 60° C.
Volume of water entering .	= 40 c.c.
Volume of flask . . .	= 310 c.c.

3. A flask of air holding 440 c.c. is cooled from 51° C. to 15° C.; a contraction of 50 c.c. takes place. Calculate the expansion of 1 c.c. of air when heated 1° C.

4. Two hundred and seventy c.c. of air when heated from 15° C. to 55° C. expanded to 310 c.c. How much would 1 c.c. of air expand if heated only 1° C.?

5. A vessel contains a small quantity of water which is boiled till all air is expelled. The closed vessel is now found to weigh 44·23 gm. but on admitting air the weight became 44·81 gm. The capacity of the vessel was 450 c.c. Find the weight of 1000 c.c. of air.

6. An exhausted flask holding 350 c.c. is found to weigh 37·24 grams. On air being admitted its weight was 37·68 gm. Calculate the weight of 1 litre of air.

7. An exhausted flask holding 650 c.c. weighs 47·23 gm. When air is admitted at 30° C. the weight is 47·987 gm. What is the weight of 1 cub. metre (*i. e.* 1000 litres) of air at 30° C.?

8. Four hundred and twenty c.c. of air at 0° C. are found to weigh ·542 grams. What is the weight of a litre of air at 0° C.?

17. ABSOLUTE ZERO.—We have seen that 1 c.c. of air at 0° C. when heated 1° C. expands $\frac{1}{273}$ c.c.

∴ 1 c.c. of air at 0° C. becomes $1\frac{1}{273}$ c.c. at 1° C.
and 273 " " " 274 " 1° C.

What would be the volume of 273 c.c. of air if the temperature is raised to 10° C.?

What, if it is raised to 100° C.?

Similarly, if the temperature is reduced we shall find that—

1 c.c. of air at 0° becomes			$1 - \frac{1}{273}$	c.c. at	$-$	1° C.
273	,,	,,	,, 272	,,	$-$	1° C.
273	,,	,,	,, 263	,,	$-$	10° C.

What would be the volume of the 273 c.c. if the temperature is reduced to $-$ 100° C.?

What, if it is reduced to $-$ 273° C.?

This seems to imply that the substance will cease to exist at $-$ 273° C. Does it mean this? If so, it implies that $-$ 273° C. is the lowest temperature that can possibly be obtained and that at this temperature all the heat has been abstracted from the body. Hence the temperature of $-$ 273° C. is called the *absolute zero*, and temperatures reckoned from this zero are called *absolute temperatures*.

(*a*) How will you convert centigrade temperatures to absolute ones? Convert 70° C., $-$ 30° C., 310° C. to absolute temperatures.

Construct a table showing how the volume of 273 c.c. of air changes as the temperature changes from 0° C. to any other temperature. You will now see that the following rule is correct—

The volume of a gas is directly proportional to its absolute temperature.

18. *Calculations.*

(1) 300 c.c. of air are heated from 10° C. to 100° C. How does its volume change?

$$10° \text{ C.} = 273 + 10 = 283° \text{ abs.}$$
$$100° \text{ C.} = 273 + 100 = 373° \text{ abs.}$$

$\therefore$ 283 c.c. heated from 10° to 100° becomes 373 c.c.

1	,,	,,	,,	$\frac{373}{283}$ c.c.
300	,,	,,	,,	$\frac{300 \times 373}{283}$ c.c.
				$= 395{\cdot}4$ c.c.

(2) What is the weight of 1000 c.c. of air at 60° C.?

273 c.c. heated from 0° to 60° becomes 333 c.c.

1 ,, ,, ,, $\frac{333}{273}$ c.c.

1000 ,, ,, ,, $\frac{333000}{273}$ c.c.

= 1220 c.c. nearly.

But both 1000 c.c. at 0° C. and the 1220 c.c. at 60° C. will weigh the same, for the weight is unchanged on heating.

∴ 1220 c.c. at 60° C. weigh 1·29 gm.

1000 c.c. ,, ,, $\frac{1 \cdot 29 \times 1000}{1220}$ gm.

= 1·005 gm.

Mathematical Exercises—II.

1. The volume of a certain mass of air is 1 litre at 27° C. What is its volume at 57° C.?

2. The temperature of 350 c.c. of air is changed from 17° C. to 75° C. What alteration takes place in the volume?

3. At what temperature will 350 c.c. of air at 0° C. become 400 c.c.?

4. At what temperature is the volume of a gas 30 per cent. greater than it is at 0° C.?

5. At what temperature is the volume of a gas 50 per cent. greater than it is at 15° C.?

6. A litre of dry air at 0° C. weighs 1·293 grams. Calculate the weight of a litre of air at (1) 10°, (2) 20°, (3) 30°, (4) 40° C.

7. A certain mass of air at 15° C. measures 350 c.c.; what is its volume at (1) 27° C.; (2) 40° C.; (3) 80° C.; (4) −15° C.?

8. Eighteen litres of air are cooled from 41° C. to 9° C. By how much will the volume diminish?

19. Other Convection Currents in the Home.—We have seen that the main convection currents in the home are those due to the fires. In some cases when the fire is not "drawing" very well some of the heated air will pass up in front of the fireplace, rise to the ceiling, and then come down again at the coldest part of the room. The direction of the current can be well seen if the fire "smokes," for the smoke rises near the chimney place, passes along the ceiling and generally descends near the window.

If the room is lighted by gas, convection currents will start at each of such sources of heat. Try and follow

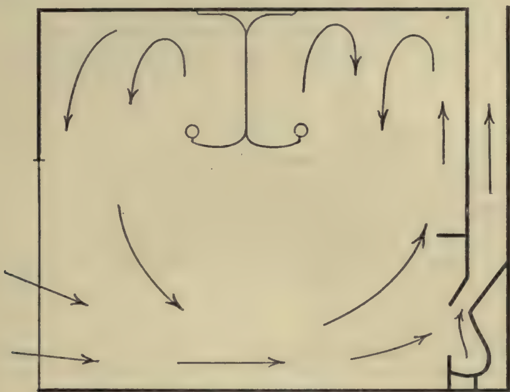


FIG. 14.

the probable course of the current. How could you make it visible?

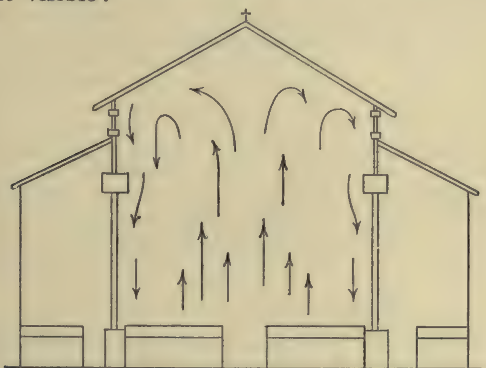


FIG. 15.

Each person in the room is a source of heat and starts a convection current. When there are many people

together in one room the current, of course, is greater, and so also is the return current of cold air. Have you ever felt the down draught from the clerestory windows in a church? Many people susceptible to cold on the head will feel it. Discuss how it can be prevented.

20. THE CAUSE AND CURE OF SMOKY CHIMNEYS.—The trouble of a smoky chimney is a very great nuisance and is of frequent occurrence. The cure of the evil does not appear to be easy, though one frequently sees numerous attempts at it. Note the very large variety of chimney pots to be seen in some streets; these all mean attempts at a cure.

Let us see how the smoky chimney is sometimes caused.

Arrange a piece of glass tubing about ·7 cm. bore near the edge of a vessel of coloured water so that the surface within the tube can be seen. Now, using a bicycle or other similar pump, blow a current of air across the top of the tube in the direction marked by the arrows and note the effect in each case on the water within the tube. Imagine this tube to be the chimney and with the wind in a certain direction the air will be blown down the tube. Which of the three directions will produce a downward current? In the chimney itself there is always the upward convection current. Whenever the force of the downward wind current is greater than that of the convection current the smoke will be blown out into the room.

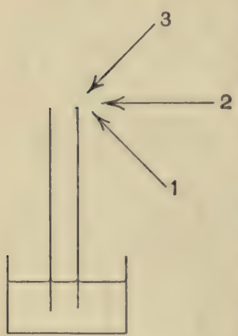


FIG. 16.

This oblique air current blowing on the top of the chimney is generally caused by neighbouring high buildings. If there are two streets running parallel, the houses of one being taller than those of the other, the smaller houses will have smoky chimneys whenever the wind reaches them from over the taller ones, for

the sloping roofs will deflect the wind downwards. With the wind in the opposite direction there will be no smoke nuisance. Look out for such a neighbourhood in your town and note down the various devices in the way of cowls, etc., that builders have tried in order

FIG. 17.

to overcome the evil. The best cure, of course, is to raise the height of the chimney, but this cannot always be done with safety when houses are badly built.

QUESTIONS AND PROBLEMS—III.

1. Why do some houses have double windows?
2. Two silver spoons, one solid and the other only plated, are placed in the same cup of tea; which handle will be the first to get hot?
3. Which heats a room better, an open fire or a stove?
4. How is the handle of a silver teapot prevented from getting too hot?
5. The inside of old English castles is cool even on the hottest summer day. Explain why this is so.
6. Why is the ice placed near the top of a refrigerator?
7. Why is an asbestos mat used by good cooks when heating milk?
8. How is the room in which you are working heated?

9. Explain the construction of the body of the "magic lantern." It is made of wood and lined either with asbestos or with tin kept away from the wood.

10. Why are sand baths used when heating some vessels?

11. Why does the wall blacken over a radiator?

12. Why does a blanket feel warmer than a sheet though both may be of the same weight?

13. Why is wire gauze used when heating a glass vessel?

14. Explain the way in which a candle-snuffer puts out a candle. How is an oil lamp extinguished?

15. What advantages does the present method of using chimneys have over the method of the primitive savages who built a fire in the middle of his "wigwam" and provided an opening in the roof for the escape of the smoke?

16. Explain how balloons are made to rise by means of hot air.

17. Why is a wooden spoon used for stirring the fruit when making jam?

18. How would you heat water so that convection currents may not be produced?

SECTION II

THE BAROMETER AND THERMOMETER

The Barometer.

21. Torricelli's Experiment.—About 300 years ago the noted philosopher and teacher, Galileo of Pisa, showed an experiment in which he proved that air has weight. He weighed an empty flask and then forced more air into it and weighed it again. It showed an increase in weight.

One of his pupils was named Torricelli; he lived from 1608 to 1647 and continued Galileo's work, afterwards becoming a teacher also. He directed two of his pupils to take a thick glass tube about 34 in. long, to close up one end and to fill it with mercury. One of them then closed the tube with his thumb and inverted it over a basin of mercury.

The experiment will be repeated before you and as it is being done answer the following questions—

(1) In filling the tube with mercury note the little bubbles on the side. What are these and how are they got rid of?

(2) When the thumb closes the tube at the top what does the tube contain?

(3) When the thumb is removed from the inverted tube does anything enter the tube either from the top or bottom?

(4) What happens to the mercury when the thumb is removed? What does the top of the tube now contain?

(5) What is the length of the column of mercury in the tube?

(6) Why does not the whole of the mercury fall out of the tube? What holds the mercury up?

The conclusion arrived at is that the atmosphere, owing to its weight, is able to hold up a column of mercury about 30 in. or 76 cm. high. This instrument is called a barometer, a word which means "weight measure."

Note what happens to this mercury when—

FIG. 18.

(1) The tube is tilted in the basin.

(2) The tube is moved further down in the basin, or more mercury is poured into the basin.

These results will show that the length of the column of mercury must be measured from the top of the mercury in the basin and when the tube is vertical.

22. VARIATION OF ATMOSPHERIC PRESSURE.—If a properly fitted up barometer be moved from place to place its height will often be found to vary considerably. The height varies from day to day. This shows that the weight or pressure of the air also varies and that it is not a constant quantity. A knowledge of its variations is very useful, for from it one may get some idea of probable changes in the weather. If a barometer be carried up a mountain it will be found that its height gradually decreases. This is as might be expected, for the higher one goes the less must be the quantity of air above us and the less must be its pressure.

23. WATER BAROMETERS.—If the pressure of the air is able to hold up a column of mercury 30 in. high, it ought to hold up a column of water of much greater height than this, for the mercury is so much heavier than water. We must first find out how much heavier mercury is than water.

Accurately measure out 10 c.c. of mercury into a weighed beaker and then weigh it. Find the weight of 1 c.c. This will give you the density of mercury.

Mercury is found to be 13·6 times heavier than water. hence the water barometer should be 13·6 times as high, that is $13 \cdot 6 \times 30$ in. = 408 in. = 34 ft. Compare this with the height of the room and you will understand why water barometers are not used. If they could be used they would be of great use for they would register very small changes of pressure. For instance, a change of 1 in. on the mercury barometer would be represented by 13·6 in. on the water barometer.

Glycerine barometers are, however, in use. Calculate how high such a barometer would be, taking into consideration that the density of mercury is 13·6, while that of glycerine is 1·27. Calculate also the change in the height of the glycerine barometer when the mercury falls 1 in.

*24. THE PRESSURE OF THE ATMOSPHERE.—Pressure is generally measured in pounds on one sq. in., that is in pounds per sq. in., or grams per sq. cm. or tons per sq. foot. The pressure of the atmosphere is generally given as the height of the column of mercury it is capable of supporting. It should, however, be easy to give the pressure of the air in the former way.

Consider a barometer whose tube has a section of exactly 1 sq. cm. (The width of the tube makes no difference to the height of the mercury column. If you cannot understand this you can fit up several barometers side by side with tubes of different sizes.) Then, if the height of the barometer be 76 cm. there will be a column of mercury 76 cm. long × 1 sq. cm. cross section—that is, there will be 76 c.c. of mercury pressing on 1 sq. cm. The density of mercury is 13·6; this means that 1 c.c. of mercury weighs 13·6 gm. Therefore, 76 c.c. of mercury will weigh $76 \times 13 \cdot 6$ gm., = 1033·6 gm. The air presses with a pressure of 1033·6 gm. per sq. cm. How would this pressure change if the height of the barometer went up 1 cm.?

The calculation of the pressure of the air in pounds per sq. in. is more difficult as it will necessitate the finding out of some constants. When the barometer stands at 30 in. and the tube is of 1 sq. in. cross section there will be a column of mercury of 30 cub. in. pressing on each sq. in. We have now to find the weight of 30 cub. in. of mercury. Do this practically.

(*a*) First find the number of cm. in 1 in.
Then the number of c.c. in 1 cub. in.
Then the number of c.c. in 30 cub. in.

Each c.c. of mercury weighs 13·6 gm.; what is the weight of the whole in grams?

(*b*) Next find by experiment the number of grams in 1 lb. and convert the weight of the mercury column in grams into pounds.

*Mathematical Exercises—III.

[Note that 1 cub. foot of water weighs 1000 oz.]

1. The height of the barometer on a certain day is 750 mm.; calculate the pressure of the air in grams per sq. cm.
2. Taking 1 in. as equal to 2·54 cm. calculate the pressure of the air in pounds per sq. in. when the barometer stands at 750 mm.
3. What is the pressure of the atmosphere in pounds per sq. foot when the barometer stands at 30 in.?
4. A barometer is constructed with a non-volatile liquid of density 1·35. What would be the height of this barometer when the mercury barometer is (*a*) 30 in.; (*b*) 76 cm.?
5. What is the height of a water barometer when the pressure of the atmosphere is 15 lb. per sq. in.?
6. What is the height of a glycerine barometer when the pressure of the air is 1100 gm. per sq. cm.?
7. If the pressure of the air is 1050 gm. per sq. cm., what is the height of the mercury barometer?

Questions and Problems—IV.

1. Determine experimentally whether the width of the tube affects the height of the barometer.

2. Balloonists carry barometers with them; what do they use them for?

3. Explain how a stone may be lifted by a "sucker." The latter consists of a piece of soft leather (fastened to a string) wetted and pressed against the stone.

4. A glass is filled with water to the brim; a card covers the top, and the glass is inverted. Explain what happens.

5. Otto von Guericke, burgomaster of Magdeburg, constructed two accurately fitting hemispheres, 1·2 ft. in diameter. When the air between them was pumped out it took sixteen horses to separate them. How do you account for this?

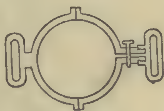


Fig. 19.

6. Aeronauts suffer a great deal when they ascend very high. Can you suggest the cause of their suffering?

7. Calculate the pressure of the air on the top of your hand. Find the area of your hand by laying it on a sheet of squared paper and tracing round it. Find the pressure of the atmosphere from the barometer.

Temperature.

25. Temperature.—In the previous pages we have had frequently to use the word temperature as meaning the difference between two bodies, one of which is hotter than the other. They are said to have different temperatures; the hotter body has the higher temperature, the colder body has the lower temperature.

We cannot always rely upon our sensations to give us accurate ideas with regard to temperature. For instance, if three vessels contain water, one being hot, another cold and the third lukewarm, and if the hands be placed one in the hot vessel and the other in the cold vessel, and they are then placed together in the lukewarm basin, the water will feel cold to the one and warm to the other. Now the same water cannot be

both cold and warm, hence our sensations are unreliable. Try the experiment yourself.

26. THERMOMETERS AND THERMOSCOPES. — Galileo, who lived and worked at Pisa, where he was born in 1564, suggested that, if a bulb be blown on a glass tube and partly filled with coloured liquid and then inverted in more of the coloured liquid, an instrument would be produced which would give better information concerning temperature than the hands did, for the air on being heated would expand and the liquid would be forced down the tube.

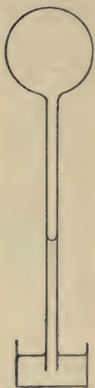


FIG. 20.

Make one of these instruments, using a flask and good cork and tube instead of a bulb. Such an instrument is now called a *thermoscope*, because it indicates that one body is hotter than another but does not show how much hotter it is. An instrument which will show how much hotter one body is than another is called a *thermometer*.

27. OTHER EARLY THERMOMETERS.—It is not quite certain that Galileo was the inventor of the first thermometer. In 1611 he suggested the use of alcohol in the instrument. Some forty or fifty years later "Florentine thermometers," as they were called, were introduced into England by Boyle. They contained alcohol in a sealed tube, but no attempt was made to exclude all air. They were marked off in spaces at the will of the maker, who used white beads stuck on the glass to mark the position of the degrees, each twelfth one having a coloured bead instead of a white one.

Early inventors experienced great difficulty in their work, as they had not yet learnt that the temperature of freezing water is constant. It was Boyle who, about 1670, proposed that this should be used as a starting point in graduating the thermometer.

In 1701 Newton constructed a thermometer containing linseed oil. The "freezing point"—that is, the

temperature of thawing snow, was marked 0 and the temperature of the blood of a living animal was marked 12. This marking gave very large degrees.

The same year a Frenchman, M. Amontons, showed that the boiling point of water was also constant, but the thermometer that he constructed was too long and too awkward to use.

Gabriel Fahrenheit was born at Danzig in 1686 and died in 1736. He studied physics with a friend of Newton and afterwards set up as a scientific instrument maker at Amsterdam. His first thermometer was graduated $-90°$ at the temperature of a mixture of ice and salt, which he supposed to be the coldest possible mixture, and $+90°$ at the temperature of the blood of a living animal. He marked the latter "blood heat." The zero point was marked "temperate." It corresponds to 16° on the present Fahrenheit scale.

In 1714 he changed his scale, taking 0° as the temperature of ice and salt, 8° as the freezing point of water, and 24° as blood heat.

In 1720 he brought out the first mercury thermometer and again revised the scale, as he found the degrees too large. He divided each into four parts and thus produced the present Fahrenheit thermometer, still used in Great Britain, the United States and Holland, on which—

$$\begin{aligned} 0° &= \text{the temperature of ice and salt,} \\ 32° &= \text{the freezing point,} \\ 96° &= \text{blood heat,} \\ 212° &= \text{the boiling point.} \end{aligned}$$

This method of graduation, however, gave variable results, hence we now only retain two fixed points—the freezing point and the boiling point.

28. The Thermometer.

Obtain a broken thermometer and note its construction. What is the size of the bore?

Does it look this size? If not, try and explain the reason. Obtain a clean flask and fill it with clean clear water and look at an object through it.

What is the size of the bulb of the thermometer? Does it look bigger or smaller?

Suggest some plan for filling the thermometer with mercury and then obtain a glass tube, blow a bulb on the end and try to fill it with water in the way you have suggested.

29. *To test the Accuracy of the Freezing Point.*

The freezing point of a thermometer is that point to which the mercury falls when the thermometer is placed in melting ice.

Fit up a funnel, containing clean ice, as in the diagram. Place the bulb of the thermometer in the ice. Note the point to which the mercury falls. Is the mark on the thermometer too high or too low? How much is the error?

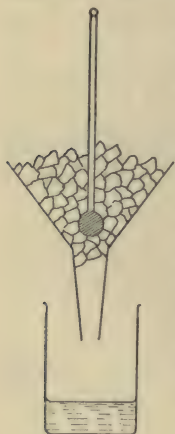


FIG. 21.

FURTHER IMPROVEMENTS IN THE THERMOMETER.—In 1730 Réaumur of Rochelle constructed a thermometer from which he took especial care to exclude air before sealing. It had a very large bulb, nearly 4 in. in diameter, and contained alcohol. Since he had seen Fahrenheit's idea disproved—that the coldest body is a mixture of ice and salt—he chose his freezing point as 0° and his boiling point as 80°. He later on reduced the size of the bulb, and in this form the instrument is still used in Russia and neighbouring parts of Europe.

In 1742 Celsius, the Swedish professor of Astronomy at Upsala, improved the thermometer by dividing the distance between the freezing point and boiling point

into 100°. This thermometer, first known as the Swedish and later as the centigrade, is now used everywhere in scientific work.

30. *To test the Accuracy of the Boiling Point.*

The boiling point of a thermometer is that point to which the mercury rises when the whole thermometer is kept in the steam of water boiling under an atmospheric pressure of 76 cm. or 30 in.

Obtain a long-necked flask; a distillation flask, as in the diagram, will suit. Fit it with a good cork through which the thermometer is placed. Add water and boil it. When it has boiled steadily note the highest point to which the mercury rises.

Is the boiling point correct? If not, what is the error?

What is the height of the barometer? If not normal (that is, 76 cm. or 30 in.), is the error in the boiling point due to the pressure?

FIG. 22

Does the correct marking of the thermometer depend upon the purity of the ice or water used?

Try an experiment to settle this question by mixing salt or other convenient substance with the ice when testing the freezing point, and with the water when testing the boiling point. There is no need for each boy in a class to use the same substance. Discuss your results afterwards and enter in an answer to the question.

Does the boiling point depend upon the whole of the stem being immersed in the steam?

In defining the boiling point of a thermometer it was stated that the whole of the thermometer should be in

the steam. Is this strictly necessary? Perform an experiment to test the accuracy of the boiling point having the stem less and less in the steam. Tabulate your results in two columns—

(*a*) the length of the mercury column showing above the cork.
(*b*) the corresponding boiling point.

At the end of the experiment write a definite answer to the question proposed.

31. Boiling Point and Pressure.—Again, when finding the boiling point care had to be taken with regard to the pressure of the atmosphere, but no such precaution was suggested when finding the freezing point. The subject will have to be returned to later, but in the meanwhile try the following experiment.

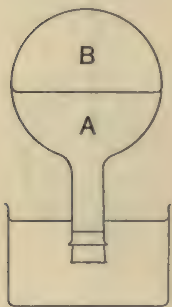


Fig. 23.

Obtain a round-bottomed flask and half fill it with water. Boil the water, and when it is boiling fast take it away from the bunsen and quickly cork it up with a good waxed cork or rubber stopper. This will stop the boiling. Now invert the flask over a vessel of water, using a suitable stand, and pour cold water on the round base. What happens to the water inside? Wait until the water is a little cooler and again pour water over it. Repeat this again and again, and when you find that the result is not obtained so readily pull out the cork and take the temperature of the water inside. It will be about 50° C. and you will therefore have been able to boil water at 50° C., though its boiling point is 100° C.

Discuss the cause of this by answering these questions and others that may occur to you.

What did the flask contain before putting in the cork?

What did the flask contain (1) at the part A, (2) at the part B (see diagram), after the cork had been inserted and the flask inverted?

When cold water was poured on what happened to the contents at B? What did B now contain? What happened in A as the result?

These questions have dealt with the contents of the flask; the following are concerned with the pressure. Let us suppose that the barometer stood at 76 cm. This means that the air was pressing down with sufficient force to hold up a column of mercury 76 cm. high. When the water began to boil, the pressure of the steam was able to push up the air so that it could now escape from the water. What was the pressure of the steam?

When the cork was placed in the flask the water stopped boiling, therefore the pressure inside had changed. Was it greater or less than 76 cm.?

When cold water was poured on the flask, the vapour inside was condensed, leaving a partial vacuum, hence the pressure again changed. Was it now more or less than 76 cm.?

The change in pressure caused the water to boil. Why was it so hard to take the cork out of the flask?

During the progress of the experiment you perhaps noticed that bubbles arose from the cork, if used, of the inverted flask. How do you account for them?

Now write down a definite statement of what you have learnt from this experiment.

32. The Hypsometer.—It is not always convenient to use a glass vessel for finding the boiling point of a thermometer, hence a special vessel has been constructed called the hypsometer. It consists of a cylindrical boiler A surmounted by a long neck B. This is surrounded by a steam jacket C, so that the steam in B

is always at the same temperature in all parts. The thermometer is held by a cork in B. From the sides of C there project (1) the outlet D for condensed water, (2) the pressure gauge E to determine whether the pressure inside the vessel is the same as the barometric pressure outside.

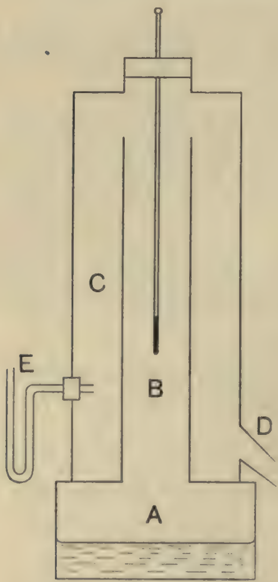


FIG. 24.

This instrument is called the hypsometer because it is more frequently used for determining the height of mountains. The word "hypsometer" means "height measure." As you rise higher and higher up a mountain the pressure of the air must become less and less. Hence one can easily determine the height of a mountain by noting the difference between the pressure at the top and that at the bottom.

The pressure changes 1 in. for a rise of 1000 ft. Since, however, the boiling point of water also changes with the pressure, the height of the mountain can be determined by noting the difference between the boiling point at the base and that at the top. The boiling point changes 1° F. for a rise of 538 ft.

33. CENTIGRADE AND FAHRENHEIT THERMOMETERS COMPARED. — Since in England both centigrade and Fahrenheit thermometers are constantly in use it may be necessary sometimes to change the readings of one into those of the other.

(*a*) Two thermometers are held in the hands. The

one in the right hand reads 95° F., the one in the left hand reads 36° C. Which hand is the hotter?

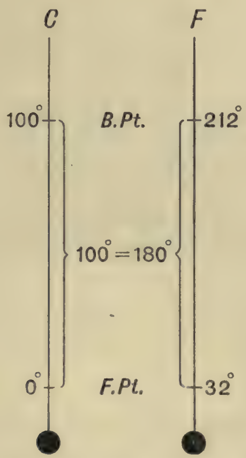


FIG. 25.

In graduating thermometers the first point marked is the freezing point—this is the starting point in all calculations.

95° F. is $95 - 32 = 63°$ above freezing point.

Now from freezing point to boiling point is 180° on the Fahrenheit scale, but 100° on the centigrade scale. Therefore—

$$180 \text{ F. degrees} = 100 \text{ C. degrees}$$

$$\text{and} \quad 1 \quad " \quad = \frac{100}{180} \quad "$$

$$\therefore 63 \quad " \quad = \frac{100}{180} \times \frac{63}{1} \quad " \quad = 35° \text{ C.}$$

The left hand was therefore 1° C. warmer than the right hand.

(*b*) Convert 60° C. to F. degrees.

$$100 \text{ C. degrees} = 180 \text{ F. degrees.}$$

$$1 \quad ,, \quad \frac{180}{100}$$

$$\therefore 60 \quad ,, \quad \frac{180}{100} \times \frac{60}{1} = 108 \text{ F. degrees.}$$

But since freezing point is marked 32° the point 108 degrees higher up will be marked $108 + 32 = 140°$ F.

(*c*) Convert 30° C., 60° C. and 90° C. to F. degrees.

Convert 59° F., 113° F. and 167° F. to C. degrees.

From these figures and your results construct a graph showing the relation between the corresponding C. and F. readings.

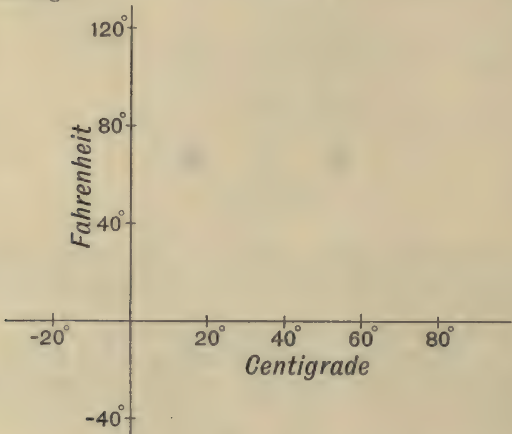


FIG. 26.

When constructing graphs note the following :—

(1) Let the scales be numbered from 0 up to the most probable extreme, *i. e.* at least 100° C. and 212° F. in the present case.

(2) Name the scales.

(3) Mark the points on the graph by a cross (×).

(4) Join the points by a line which should be smoothed if the figures are obtained from experiments.

(5) On some available space, state what the graph represents.

Having completed this particular graph, see whether the points have arranged themselves in a regular manner. In this case they should form a straight line. If they do not, it points to the fact that you have made errors, most probably in your calculations. A graph is often useful in pointing out the existence of these errors.

In the next place extend the graph line and see whether it will pass through the points—

(*a*) 100° C. = 212° F. = boiling point.
(*b*) 0° C. = 32° F. = freezing point.

Mark these points f.p. and b.p. on your graph.

Could you have constructed this graph without having made any calculations at all?

The graph can also be used for converting one reading into another without doing the calculations.

Mathematical Exercises—IV.

1. Convert 158° F. into C. degrees and 40° C. into F. degrees.
2. By means of a graph find what temperature on the C. scale will correspond with 0° F.
3. Convert 10° C., 30° F., 60° C. to Réaumur degrees.
4. Construct a graph for converting C. degrees to R. degrees, and by means of it find the equivalent of 30° R. and 60° R. in C. degrees.
5. Convert − 20° F. to centigrade degrees.
6. What temperature is represented by the same number on both the centigrade and Fahrenheit scales?
7. Two thermometers exposed to the same source of heat read 37° C. in the one case and 98·4° F. in the other. What is the difference, if any, between their readings?
8. A standard centigrade thermometer reads 44° C., while a Fahrenheit thermometer reads 110° F. when placed in the same vessel of water. What is the error of the latter thermometer?
9. What temperature on the Fahrenheit thermometer is represented by half the number on the centigrade thermometer?
10. A certain vessel of water rises 20° C. in temperature when heated; express this rise on the (1) Fahrenheit, (2) Réaumur scale.

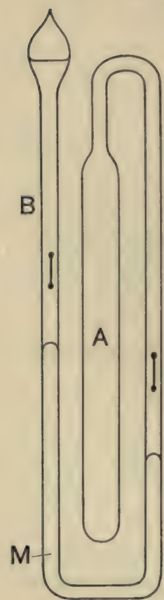
11. From the figures given in § 32 determine the increase in altitude corresponding to a fall in temperature of 1° C.

12. On the top of Mt. Everest water boils at 72° C. Find the height of the mountain.

13. A hypsometer was taken to the summits of several mountains with the following results for the boiling point of water: Mont Blanc, 85·5° C.; Ben Nevis, 95·6° C.; Fujiyama, 87·8° C.; Ruwenzori, 83·2° C. Compare their heights.

14. From the following figures construct a graph showing the correction to be applied to the boiling point of a thermometer if the barometer does not stand at 760 mm.

Barometer.	b.p.	Barometer.	b.p.
633·6 mm.	95° C.	733·2	99° C.
657·4 ,,	96° ,,	760·0	100° ,,
681·9 ,,	97° ,,	787·7	101° ,,
707·1 ,,	98° ,,		



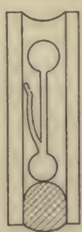


FIG. 27.

34. THERMOMETERS FOR SPECIAL PURPOSES.—Gardeners and others are often anxious that their greenhouses, etc., should neither get too hot in the day nor too cold at night. For their use maximum and minimum thermometers are supplied.

A maximum thermometer is one which indicates the highest temperature attained during any given period.

A minimum thermometer is one which indicates the lowest temperature reached during any given period.

We first read of them in 1770, but it was not till 1782 that the well-known *Six's thermometer* was described.

The bulb A and part of the stem contains alcohol. When the alcohol expands, the mercury thread M is

pushed along and its level on the B side is raised. Above the mercury in B there is more alcohol.

The movement of the mercury alters the position of a dumb-bell-shaped index which remains at the spot to which it is pushed, since it is provided with a steel spring. How would you bring the steel index back to its proper level when the mercury receded?

In 1790 *Rutherford* made his maximum thermometer which is still in use. Four years later he brought out his minimum thermometer.

If possible, obtain these two thermometers and describe their construction.

Later on *Negretti and Zambra*, scientific instrument makers of London, brought out a thermometer in which there was a constriction of the tube just above the bulb. This was not sufficiently small to prevent the mercury passing through it when forced by its own expansion. It was so small, however, that the thread of mercury which had risen above the constriction was not, by its own weight alone, able to pass back along the constriction on the contraction of the mercury when cooling.

Doctors still use a modification of this thermometer. Since they do not have to measure blood temperatures higher than 105° and lower than 93° these are the highest and lowest points on the "*clinical*" *thermometer.*

How does the doctor get the mercury back past the constriction again?

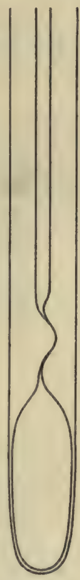


FIG. 28.

35. THE THERMOGRAPH.—In many cases maximum and minimum thermometers do not give all the information desired. For instance, if it is necessary to know at what time the maximum (or minimum) temperature was reached, these thermometers are of no use. Thermographs are so constructed that they register the temperature attained at each moment of the day.

The liquid which takes the place of the mercury in an ordinary thermometer is contained in a metal box A. This box is made with curved sides so that when the liquid expands the box has to straighten out in order to increase its internal volume. One end of the box (N) is fixed so that the straightening motion is all at the other end. This motion moves one end of a lever balanced about the point L so that the part B is much shorter than the part C. If C is 10 times B, a small movement of the end of A will be magnified 10 times at the end of C. A second and similar lever is fixed to the end of C so that the point P, to which a small pen

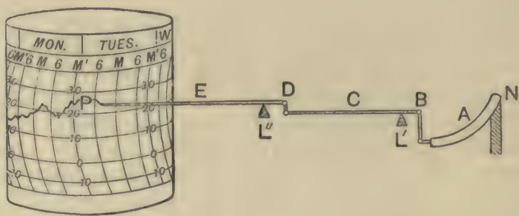


FIG. 29.

is fixed, moves 100 times as much as the end of the box moves. The motion of P leaves a continuous mark on a sheet of paper fixed round a drum. The drum is fitted with clockwork by means of which one complete revolution is made in one week. The graph paper is ruled horizontally for degrees (temperature), and vertically for time, the "time" lines being at such distances that the pen moves from one to the next in three hours.

How many "time" lines are there on one sheet?

Why is it that the "time" lines are not exactly vertical but parallel arcs of circles.

Suggest some circumstances in which the use of such a thermograph as this would be advantageous? What classes of people are likely to buy them?

36. The Thermostat.

This is an instrument constructed to keep the temperature of any place constant. It consists essentially of a thermometer in which the rise (or fall) of the mercury cuts off (or increases) the supply of gas (or electricity) to the source of heat.

Suggest some classes of people who might use such an instrument.

Questions and Problems—V.

1. What are the chief defects of Galileo's thermometer?
2. It is said that it is not possible to boil eggs on the top of some mountains. How do you account for this?
3. Sir Samuel Baker, who searched for the source of the Blue Nile in Abyssinia, frequently mentions that he "boiled his thermometer." What did he mean; how did he do it and for what purpose?
4. Most advances in science have not been made in sudden jumps but by a slow accumulation of small discoveries made by many different observers. Illustrate this from the history of the thermometer.
5. What led Fahrenheit to divide up his thermometer stem in the way he did? What were his reasons for using such out-of-the-way numbers as 32 and 212?

Mathematical Exercises—V.

1. The temperature of a room falls 10° F.; express this on the centigrade scale.
2. A home-made thermometer had the two fixed points marked; they were found to be 22 cm. apart. When this thermometer had stood for some time in the laboratory the mercury was found to be 3·8 cm. above the lower point. What was the temperature of the room on the C. and F. scales?
3. Alcohol boils at 78·2° C. and freezes at – 130° C.; what are these temperatures on the Fahrenheit scale?
4. Taking the range on a clinical thermometer as 90° F. to 110° F., express it in the centigrade scale.

5. A maximum thermometer is graduated in twentieths of a degree between 35° C. and 50° C. What is this range on the Fahrenheit scale and what is the value of each division of the scale?

6. The volume of a gas is kept constant; how will the pressure exerted by the gas be affected when the temperature is changed? If the temperature changes from 15° C. to 20° C. how will the pressure change?

*7. What correction, if any, has to be applied to the boiling point of a thermometer if, when it is determined, the barometric height is not 760 mm.? [See question 14 of Ex. IV.]

*8. What temperatures between 50° F. and 60° F. are expressed by whole numbers on both the centigrade and Fahrenheit scales?

*9. A thermometer is constructed to read 15° in melting ice and 45° in steam. Construct graphs to enable you to convert readings on this thermometer into Fahrenheit and centigrade readings.

SECTION III

EXPANSION OF SOLIDS, LIQUIDS AND GASES

37. Expansion.—In reviewing the work we have already done we shall note that on several occasions we came across the fact that bodies, when heated, expand and that when cooled they contract. We saw that the formation of convection currents was due to the expansion of air, and we measured how much it expanded. We have just seen that the expansion of mercury is made use of in the making of thermometers.

When we look around us we shall see that the results of expansion are common. All bodies expand more or less, and in buildings and other construction works this expansion must be allowed for. For instance, in laying railway lines, small spaces must be left between the ends of the rails to allow for expansion in summer. Can you give some other examples?

Suppose you were engaged in some such work and had to use metals and hence had to allow for their expansion, it would be necessary for you to know how much room to allow and whether the same space had to be allowed for all metals—that is, whether they all expand alike.

It is important for us, therefore, to be able to measure how much a body will expand.

38. The Expansion of Gases.—We have already considered the expansion of air when that expansion has been produced by heat. Revise § 15 on this subject.

Of course, other gases may not expand the same amount as air. Therefore find how much 1 c.c. of coal-gas expands when heated 1° C. If you are working in

classes others may find the expansion of 1 c.c. of carbon dioxide or hydrogen when heated 1° C. Remember that both gases must be dried before using them. When finished compare your results and determine whether the expansion of all the gases tried is the same.

Expansion and contraction of gases can be produced, however, by other means than a change of temperature.

In an ordinary pop-gun the air is compressed by forcing in the piston. The old philosophers, in considering similar experiments, said that the air had a "spring" and that the spring of the air caused it to force the cork out of the pop-gun. Modern philosophers use the word "elasticity" instead. It would be well to consider this question of the decrease in the volume of the air by the application of some pressure upon it.

39. Boyle's Law.—Robert Boyle, son of the first Earl of Cork, lived from 1627 to 1691. While at Oxford he published in 1660–1662 an account of a series of experiments he had been conducting, and among them was one on the expansion and contraction of air owing to changes of pressure. He used a bent tube composed of a short closed limb and a longer open one. He placed some mercury in the bend so that the two levels were alike. This enclosed a volume of air at atmospheric pressure.

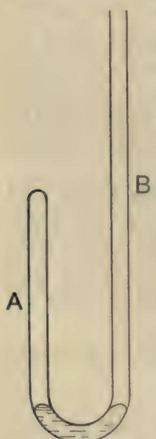


Fig. 30.

(Explain why the air in A is exerting the same pressure as the air in B.)

He then added more mercury in the open tube until the volume of the enclosed air was exactly half what it was before. To obtain this result he had to have the mercury level in the open tube 29 in. above that in the closed limb. The pressure now exerted on the enclosed air was 29 in. of mercury together with that due to the barometric pressure of the air, which was also found to be 29 in. This means, that on doubling the pressure he had

halved the volume of the air. Similarly he found that on trebling the pressure he had obtained a volume one-third of the original volume.

He then stated the law he had discovered. **The volume of gas is inversely proportional to the pressure applied to it, if the temperature be kept constant.**

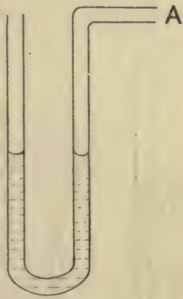


FIG. 31.

40. THE PRESSURE GAUGE.—The U-tube containing water, mercury or oil is often used for measuring pressures.

Obtain a U-tube as in the diagram and half fill it with water. Why is the level of the water in each limb the same?

Attach the end of the tube A to the gas tap and turn on the gas. Do the water levels change? Make a sketch of the result and explain how you can measure the pressure of the gas.

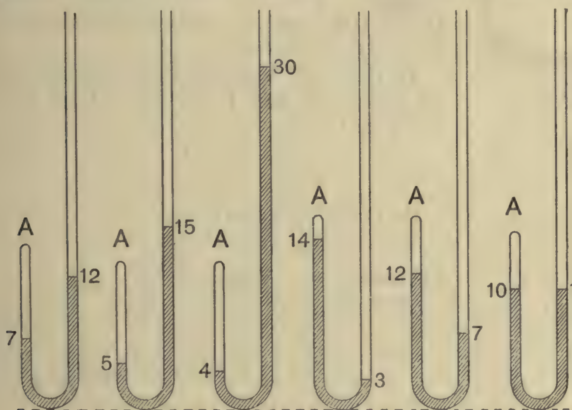


FIG. 32.

What is the pressure in each case exerted by the air enclosed in the tube A (fig. 32) when the level of the mercury above the bench is as marked? The barometer that day stood at 75 cm.

41. "BOYLE'S" APPARATUS.—The apparatus used by Boyle himself is hardly convenient, as it necessitates the use of additional mercury. The apparatus generally used consists of—

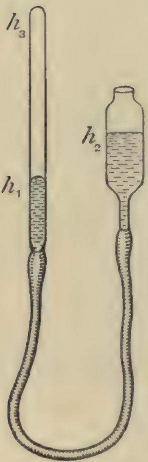


FIG. 33.

(*a*) A fixed closed tube.

(*b*) A wider, open and movable tube [the two connected by rubber tubing filled with mercury], together with a scale for measuring differences of level. When the level of the mercury is the same in both tubes the volume of the air is measured; its pressure is that indicated by the barometer, which must be read at the time of performing the experiment. If the movable tube be now shifted downwards the volume of the air increases and the pressure diminishes. Let both be measured exactly. This can be repeated several times, the movable tube being shifted up or down as desired.

In this way a number of readings may be obtained, and these should be tabulated as under.

BOYLE'S APPARATUS.

h_1.	h_2.	Pressure. $h_2 - h_1 + P$.	Volume. $h_3 - h_1$.	

P = barometric pressure.

We have next to obtain the law connecting these two sets of readings.

First—to see whether such a law exists at all.

The best way to do this is to construct a graph showing the relation between the two sets of quantities.

If the resulting graph is a regular curve, then there is a law connecting the two quantities.

Next—to find out the law. The form of the graph will give some indication of the law.

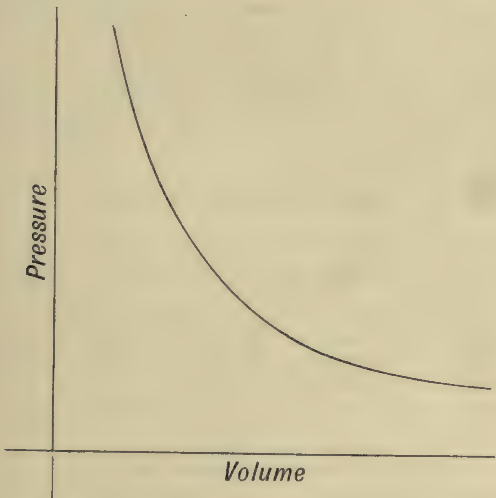


FIG. 34.

(1) Construct a graph in which $\frac{y}{x}$ is a constant, x and y being the two series of quantities used to form the graph. Suppose the constant is 6, then if—

$$\begin{array}{llllll} x = & 2 & 4 & 6 & 8 & 20, \text{ etc.} \\ y = & 12 & 24 & 36 & 48 & 120, \text{ etc.} \end{array}$$

Use these figures and others obtained similarly to form the graph.

(2) Construct another graph in which xy is a constant.

Which of these two graphs is most like the one obtained from the results of the experiment?

If you think it is the second, try whether the product of pressure and volume gives a constant. There is room for the products in the fifth column of the table.

In work of this kind it is always best to arrange your results in a definite order, taking care, however, to keep connected pairs of pressure and volume together. You will not find the products all exactly alike. The errors may be due (1) to errors in the experiment, in which case they will not alter regularly as the pressure goes up, or (2) to the law assumed not being the correct one. In this case you will find the products steadily increasing as you look up or down the column. If the errors are small they may be neglected.

What is the law deduced from your figures?

*Additional Experiment.

1. Devise and carry out an experiment to verify the following law—

> When the volume of a given mass of gas is kept constant, the increase in pressure, due to a rise in temperature, is directly proportional to the absolute temperature of the gas.

Calculate the "coefficient of increase in pressure."

Questions and Problems—VI.

1. Does the tea stand at the same level in the spout as in the teapot itself?

2. We sometimes see a tap fixed near, but not at, the top of a pipe. Is there any advantage in this?

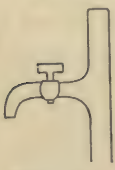


Fig. 35.

3. An inverted bottle was pushed under water until it became half full of water, no air being allowed to escape. If the barometer stood at 75 cm. what was the pressure of the air in the bottle?

4. The bars at the top of the kitchen gas stove are not firmly fixed; why is this?

5. A barometer contains a small quantity of air above the mercury so that it reads 30 in. when the true height should be 30·3 in. What else must you know

about the barometer in order to find out the true height when it reads 28 in.?

6. A glass tube open at one end and closed at the other contains some air locked in by a column of mercury 10 cm. long. When the tube is held vertically with the open end upwards the length of the air column is 24 in. When the tube is held horizontally the length of the air column is 32 in. long. What is the height of the barometer?

7. Do you think this would make a good instrument to use instead of a barometer?

8. Explain the use of the manometer or pressure gauge when attached to the hypsometer.

9. Explain why it is that when blowing up a cycle tyre it is quite easy to use the pump at first but becomes much harder towards the end.

Mathematical Exercises—VI.

1. A mass of gas measures 25 c.c. when the pressure on it is that due to 27 cm. of mercury. What will the volume be when the pressure is that due to (1) 30 cm., (2) 60 cm., (3) 90 cm. of mercury?

2. A certain mass of gas measures 60 cub. in. when the barometer stands at 30 in. What will be the volume of the gas when the pressure upon it is increased by the addition of 20 in. of mercury?

3. Some gas has a volume of 14 cub. in. when the pressure is 6·5 in. of mercury greater than that of the atmosphere. The same mass of gas has a volume of 21 cub. in. when the pressure is less than that of the atmosphere by 6 in. of mercury. What was the height of the barometer at the time?

4. One thousand litres of air at 0° C. and 760 mm. barometric pressure weigh 1293 gm. Calculate the weight of 250 litres at 0° C. when the pressure is 70 cm. of mercury.

5. A certain quantity of air is at a pressure of 30 cm. of mercury. How must the pressure be altered so that the volume may be (*a*) 50 per cent. more, (*b*) 50 per cent. less?

6. The column of gas in the closed limb of a Boyle's tube is 15 cm. long when the barometer stands at 75 cm. How long a column of mercury must be poured into the open limb so as to make the column of air (*a*) 10 cm., (*b*) 7·5 cm., (*c*) 5 cm. long?

7. A barometer with a "vacuum" of 15 cm. contains a small quantity of air. The height of the barometer is 75·95 cm. when it should have been 76·1 cm. What was the pressure exerted by the enclosed air? If the barometer falls apparently to 74·5 cm. what is its true height?

42. THE EXPANSION OF WATER.—*To determine how much* 1 *c.c. of water expands when heated* 1° *C.*

A flask is fitted up, as in the diagram, with a good cork and bent tube. It is filled with water to the end of the tube and the amount of water it holds noted down. Its temperature is also taken. Let us suppose that it holds 300 c.c. at 15° C. Now quickly place it in a vessel of hot water and let the overflow due to expansion be collected in a burette already containing some cold water. The difference between the levels of the water in the burette at first and at the end will give the expansion. Suppose these readings were 48 and 44·4, then the expansion is 3·6 c.c. As soon as the overflow ceases, take out the cork and take the average temperature of the water inside. Suppose it is at 48° C. Now according to these figures—

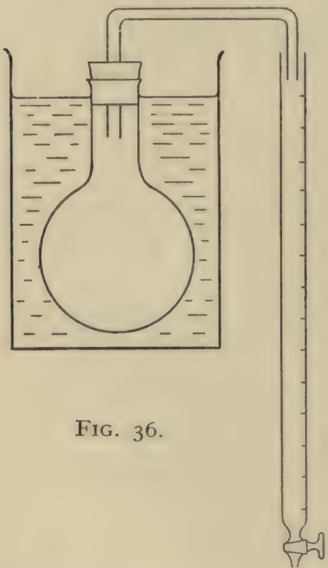


FIG. 36.

300 c.c. of water heated 33° C. expands 3·6 c.c.

$$1 \quad ,, \quad ,, \quad 1 \quad ,, \quad \frac{3\cdot 6}{33 \times 300} = \cdot 00036 \text{ c.c.}$$

While performing the experiment yourself answer the following questions and embody the answers in your notes.

(1) Why is the experiment commenced with the tube full?

(2) What disadvantages would there be in heating the flask too much?

(3) Why was it necessary to commence with some water in the burette?

(4) Would it be equally good to take the temperature of the bath instead of that of the flask?

(5) Was it quite correct to say that 300 c.c. had been heated 33°. What difference would it make to the answer if the more correct number had been used?

Mathematical Exercises—VII.

1. A flask containing 300 c.c. of water is heated from 0° to 15° C. when ·21 c.c. overflow. Calculate the expansion of 1 c.c. of water when heated 1° C.
2. A flask contains 350 c.c. of water at 4° C. and 354·18 c.c. at 50° C. Determine how much 1 c.c. of water expanded when heated 1° C.
3. When heated from 10° C. to 40° C., 250 c.c. of water expanded so that the volume became 251·11 c.c. Determine the expansion of 1 c.c. when heated 1° C.
4. A flask containing 400 c.c. of water is heated from 15° C. to 65° C. when 7·55 c.c. of water overflowed. Calculate the expansion of 1 c.c. when heated 1° C.

*43. The Weight Thermometer Method.—*To find the expansion of 1 c.c. of water when raised from 20° C. to 60° C.*

Fig. 37.

The weight thermometer is a vessel which can be exactly filled with a liquid. It may be either a bottle with a hole through (or a slot in) the stopper, or a vessel like that in the diagram. The vessel, whose weight when empty is known, is first filled with the liquid at a known temperature.

How would you arrange that it is exactly filled at

20° C.? Replace the stopper if it is out, carefully dry the outside of the vessel and weigh it.

Repeat this with the temperature at 60° C.

Results.

Temperature at first . . .	= 20° C.
Temperature at end . . .	= 60° C.
Weight of bottle	= B gm.
Weight of bottle and water at 20° C.	= W ,,
,, ,, ,, 60	= W ,,
Weight of water alone at 20° C. .	= W − B gm.
,, ,, ,, 60° C. .	= W − B ,,

Calculation.

Let us suppose that 1 c.c. of water at 20° C. weighs d grams, then—

d grams of water at 20° C. occupy 1 c.c.

1 gram ,, ,, occupies $\frac{1}{d}$ c.c.

(W − B) ,, ,, ,, $\frac{(W - B)}{d}$ c.c.

Similarly (w − B) ,, ,, $\frac{(w - B)}{d}$ c.c.

Imagine that the bottle and the water it contains at 60° is cooled to 20° C. This volume of water will expand and fill the bottle if heated to 60°.

Hence

$$\frac{w - B}{d} \text{ c.c. heated } 40^\circ \text{ expand } \frac{W - B}{d} - \frac{w - B}{d} \text{ c.c.}$$

$$= \frac{W - B - w + B}{d} \text{ c.c.}$$

$$= \frac{W - w}{d} \text{ c.c.}$$

$$\therefore 1 \text{ c.c. ,, } 1^\circ \text{ expands } \frac{W - w}{d} \times \frac{1}{40} \times \frac{d}{w - B} \text{ c.c.}$$

$$= \frac{W - w}{40(w - B)} \text{ c.c.}$$

44. Class Results.—When a whole class is working at one experiment better results can be obtained by comparing one result with another.

(1) Small errors will occur even with good workers. These can frequently be eliminated by taking the average of several results. The average can only be taken, however, when there is no regularity in these errors.

(2) In the present experiment there would be some variation among different workers in the temperature to which the water was raised. Hence when all experiments are finished let the answers be arranged in the order of their *final* temperature. When so arranged you may perhaps see a gradual increase in the answers. This will show that the expansion increases (or decreases) as the temperature rises. Does it do so?

MATHEMATICAL EXERCISES—VIII.

1. A certain flask weighs 102·36 gm.; when filled with water at 20° C. it weighs 177·03 gm. After being heated to 70° C. the flask and its contents were found to weigh 175·62 gm. From these results calculate the apparent expansion of 1 c.c. of water when heated 1° C.
2. A bottle weighs 12·3 gm. when empty and 312·6 gm. when filled with ice-cold mercury. On being heated to 100° C., 4·62 gm. of mercury overflowed. Calculate the apparent coefficient of expansion of mercury.
3. A glass bottle when quite full at 0° C. holds 100 c.c. What volume of boiling water will it hold?
4. A weight thermometer contains 106·02 gm. of mercury at 15° C. and 104·64 gm. at 100° C. Calculate (*a*) the apparent coefficient of expansion of mercury, and (*b*) the coefficient of cubical expansion of the glass of which the bottle was made.

45. THE CONTAINING VESSEL.—When experimenting with liquids it is necessary to have a vessel to hold the liquid. Has the vessel any effect on the expansion of water?

To determine this, fit up a flask with a good cork and a glass tube, of narrow bore, as in the diagram (fig. 38). Fill the flask with water and arrange so that the water reaches half way up the tube. If the water level is not

steady find out the cause of the error and correct it. Then mark the level in some way and plunge the flask into a vessel of hot water. Note carefully what happens and try to explain it as accurately as you can.

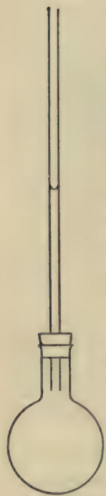


FIG. 38.

46. THE IRREGULAR EXPANSION OF WATER.—A previous experiment has perhaps shown you that the expansion of 1 c.c. of water when heated 1° C. varies with the temperature to which the water was raised. This can be shown much more conclusively by means of a special piece of apparatus which is so constructed as to render the effect of the expansion of the vessel of no account.

Obtain a long glass tube ending in a bulb at least 1 in. in diameter. Weigh the tube empty and then fill the bulb and 3 or 4 in. of stem with water and weigh it again.

If now we place some mercury in the bulb with the water we shall find that, on heating, the glass will expand and make the bulb larger, and the mercury will expand and make that part of the bulb holding the water smaller. Knowing, however, that mercury expands seven times as much as glass, we can so arrange matters that the expansion of the mercury is exactly equal to that of the glass bulb. Then the part of the bulb holding the water will always be of the same size no matter what its temperature may be. What volume of mercury will have to be put into the bulb to produce this effect?

Suppose the weight of the bulb and tube empty was 20 gm. and when filled was 30·5 gm. What was the volume of the bulb? What volume of mercury must be put in? What would be the weight of this mercury? One c.c. of mercury weighs 13·6 gm.

You can now prepare a tube in which the expansion of the glass vessel is counteracted.

When the tube is ready fill the bulb and a part of the stem with water, place it in a vessel of water and note the height of the water level in the tube. (What is the best way of doing this?) Now slowly raise the temperature of the water a few degrees, stir it well, and after waiting a few minutes to let the whole bulb attain the same temperature, note again the height of the water level. Repeat this several times, keeping a note of the results—temperature and height.

Now reduce the temperature in the same way and again note the corresponding temperatures and water levels. Repeat this as often as possible and construct a graph from the results. In a simplified experiment such as this it would be difficult to get very accurate results, but it will enable you to note some curious points about the expansion and contraction of water. What are these?

For accurate results we must look at the work of some noted scientist. Rossetti in 1867–1869 determined the volume of 1 gm. of water as it was heated from 0° C. to 100° C. Some of his results are as follows—

47. VOLUME OF ONE GRAM OF WATER.

Temp.	Volume.	Temp.	Volume.	Temp.	Volume.
Deg. C.	c.c.	Deg. C.	c.c.	Deg. C.	c.c.
0	1·00013	9	1·00018	20	1.00174
1	1·00007	10	1·00025	30	1·00425
2	1·00003	11	1·00034	40	1·00770
3	1·00001	12	1·00045	50	1·01195
4	1·00000	13	1·00057	60	1·01691
5	1·00001	14	1·00070	70	1·02256
6	1·00003	15	1·00084	80	1·02887
7	1·00007	16	1·00100	90	1·03567
8	1·00011	17	1·00116	100	1·04312

Construct a graph from these figures showing the expansion of water from 0° C. to 17° C.

Examine the graph and state in words all that the graph teaches you with regard to the expansion of water at low temperatures.

48. Maximum Density of Water.—The density of a body is the mass of 1 c.c. (or unit volume) of it. As you perceive, the density of water changes as the temperature alters. Calculate the density at one or two different temperatures. Does the density work out to be more or less than 1 gm. per c.c.? At what temperature is the density greatest?

A body will have its maximum density when a given volume of it contains the maximum quantity of matter. This we see occurs at one particular temperature in the case of water. At what temperature will water have its maximum density?

What is the weight of 1 c.c. of water at 4° C. If water at 4° C. is poured carefully on water at 0° C. would it float or sink?

At what other temperature will water have the same density as it has at 0° C.?

49. Hope's Experiment.—This is an experiment in which a cylindrical metal vessel of water is cooled by a layer of ice surrounding it half way between the top and bottom, as in the diagram.

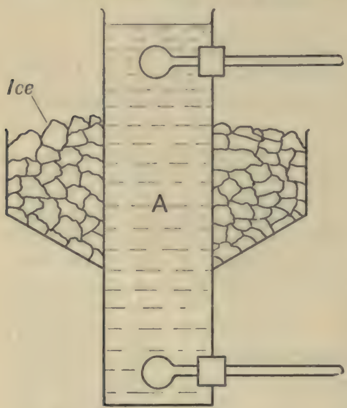


Fig. 39.

Let us suppose that the initial temperature of the water is 10° C. The water at A will be cooled. Will it expand or contract? Will it become denser or less dense? Will it rise to the top or fall to the bottom? Sketch the direction of the convection currents produced. What do you think will be the temperature of different parts of the water a few minutes after cooling has commenced?

Suppose, now, that the temperature of the water at A

has reached 4° C., what will be the probable temperatures at the top and bottom of the vessel?

If the temperature at A falls below 4° C. will the water at A become denser or less dense? Will it rise or sink?

When the temperature at A reaches 0° C. what will be the probable temperatures at the top and bottom?

Tabulate the probable changes in the temperature in different parts of Hope's apparatus as the central part is steadily cooled from 10° C. to 0° C.

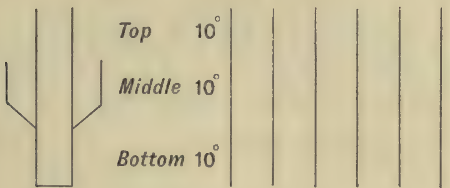


FIG. 40.

50. A WATER THERMOMETER.—We have previously noted that a water thermometer is never used. Perhaps we can now find one of the reasons for this.

By the side of the graph just constructed rule two vertical lines about 5 mm. apart. Let these represent the stem of a thermometer; add on the bulb where convenient. Transfer the points on the graph corresponding to 1°, 2°, 3° . . . horizontally along to the thermometer stem; mark and number the points. This will give us the relative positions of the graduations of a water thermometer. What do you note about them? What are some of the disadvantages in using water in a thermometer?

Is the expansion of water any more regular at higher temperatures? Would water be any better for a thermometer if used only between 30° and 90° C.? To be able to answer this it is necessary to construct a graph for the expansion of water between 10° C. and 100° C.

51. MERCURY THERMOMETERS.—We have seen that water has its disadvantages when used in a thermometer. Is mercury any better? Proceed in a similar way to construct a graph showing the expansion of mercury between 0° C. and 100° C. and mark off the relative graduations on a "thermometer stem."

The following figures are from experiments by Henri Regnault in 1842. Henri Regnault was a French chemist, a pupil of Liebig's. He became Professor of Chemistry at the Collège de France and was a director of the Sèvres porcelain works. He is especially noted for his experiments on physical problems of interest and use to the chemist. His accuracy is such that many of the quantities then determined by him have remained uncorrected by any of the workers since.

52. EXPANSION OF MERCURY.

Temp.	Volume.	Temp.	Volume.
Deg. C.	c.c.	Deg. C.	c.c.
0	1·000	50	1·090
4	1·007	60	1·108
10	1·018	70	1·126
20	1·036	80	1·145
30	1·054	90	1·163
40	1·072	100	1·181

What do you note with regard to the expansion of mercury?

Of what advantage is this in the construction of thermometers? State all the advantages you can think of in using mercury for thermometers.

QUESTIONS AND PROBLEMS—VII.

1. Why does the kettle of water often "boil over" before it actually boils?

2. Explain what happens when an air balloon is placed in front of a hot fire.

3. Why does a pond freeze first on the surface?

4. The coefficient of expansion of mercury is ·00018,

while that of alcohol is ·00108. Compare the relative advantages of mercury and alcohol as liquids for filling thermometers.

*5. The accompanying diagram represents the arrangement for the supply of hot water to baths, etc., in use in many houses.

How is the flow of water produced?

Mark the direction of flow in each of the pipes.

Why do the "flow" pipes leave at the top of the boiler and cylinder.

Why do the "return" pipes join on at the bottom of the boiler and cylinder?

Why does the "return" pipe from the bath join on higher up the cylinder?

What is the advantage in using a circulating cylinder as well as a boiler? If no cylinder is used, what alteration will have to be made to the boiler?

What is the purpose of the expansion pipe? Before answering imagine that the whole system is filled with cold water and that then the fire is lighted and the boiler heated.

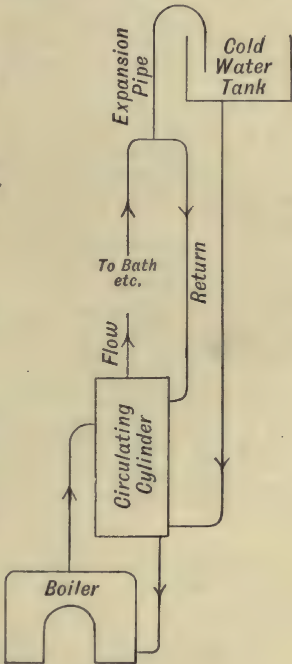


FIG. 41.

53. COEFFICIENTS OF EXPANSION OF LIQUIDS.—The coefficient of expansion of a liquid is the expansion of 1 c.c. (or unit volume) when heated 1° C.

Alcohol (spirits of wine) .	= ·00110
Aniline	= ·00085
Benzine	= ·00124
Chloroform	= ·00126
Ether	= ·00163
Mercury	= ·00018
Turpentine	= ·00094

Mathematical Exercises—IX.

1. A flask holds 220 c.c. of a certain liquid at 0° C. When the flask is heated to 60° C. 20 c.c. overflow. Calculate the apparent expansion of 1 c.c. of the liquid when heated 1° C.

2. A flask holding 320 c.c. of alcohol is heated from 15° C. to 45° C. It is found that 10·4 c.c. overflow. Calculate the expansion of 1 c.c. when heated 1° C.

3. A flask contains 70 c.c. of mercury at 15° C. What would the volume of the mercury be when heated to 65° C.?

4. To what temperature must 60 c.c. of aniline be heated in order that the volume may be 63 c.c., the initial temperature being 16° C.?

5. A certain volume of chloroform is cooled from 40° C. to 10° C. What is the decrease in volume, the initial volume being 35 c.c.?

*6. A flask holds 60 gm. of alcohol at 10° C. and 57 gm. at 60° C. Calculate the coefficient of expansion of alcohol.

*7. A bottle holds 250 gm. of mercury at 0° C. How much will overflow if it be heated to 100° C.?

*8. The weight of 1 c.c. of mercury at 0° C. is 13·596 gm. What will be the weight of 1 c.c. at 100° C.?

54. Real and Apparent Coefficients of Expansion.—When a vessel of water is heated two things occur—

(1) The vessel expands, making the volume of liquid appear less.

(2) The liquid expands, making its volume appear greater.

The real expansion of the liquid is therefore always greater than the apparent expansion.

$$\begin{array}{c}\text{Real expansion}\\ \text{of liquid}\end{array} = \begin{array}{c}\text{Apparent expansion}\\ \text{of liquid}\end{array} + \begin{array}{c}\text{Expansion}\\ \text{of vessel.}\end{array}$$

Suppose a vessel contains 500 c.c. of liquid (aniline) at 0° C. and when heated to 40° C. the apparent expansion of the liquid was 17·8 c.c., while the real expansion was

18·3 c.c. This indicates that the expansion of the glass was ·5 c.c.

Real expansion of liquid		Apparent expansion of liquid		Expansion of glass
18·3 c.c.	=	17·8 c.c.	+	·5 c.c.

Calculate in each case the expansion if they had only been heated 1° C.

Next calculate in each case the expansion of 1 c.c., that is, the coefficient of expansion. What do you note about these three?

MATHEMATICAL EXERCISES—X.

The real coefficient of expansion of a liquid is equal to the sum of its apparent coefficient of expansion and the coefficient of expansion of the material of which the vessel is made.

1. A bottle weighs 20 gm. when empty, 70 gm. when full of a liquid at 10° c., and 67·8 gm. when filled with the liquid at 50° C. Calculate the real and apparent coefficients of expansion of the liquid, the coefficient of expansion of glass being taken as ·000025.

2. How much mercury must be placed in a 50 c.c. glass bottle so that the space above the mercury may be the same at all temperatures?

3. A glass bottle contains 74·68 gm. of water at 20° C. and 73·36 gm. at 65° C. Calculate the real coefficient of expansion of water between these temperatures.

4. From the table in § 47 calculate the coefficient of expansion of water at each temperature from 0° C. to 20° C. Construct a graph to illustrate the results.

The Expansion of Solids.

55. SOLIDS EXPAND WHEN HEATED.—There is very little difficulty about the expansion of liquids and gases for their increase in size when heated is easily visible, but with solids there is a difference. Solids expand very little indeed, and in measuring the expansion we

have to measure a quantity which cannot be directly seen.

Before attempting to measure the expansion try this experiment, in order to show that solids do expand when heated.

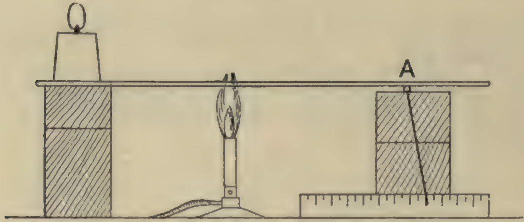


FIG. 42.

Arrange a metal rod as in the diagram. It is supported at each end by blocks of wood. One end, B, is held firmly by a heavy weight, the other rests on a glass tube A, which ends in a pointer. When the rod is heated it expands in the direction of A, and causing the tube to revolve, makes the pointer move. In which direction will it move? To

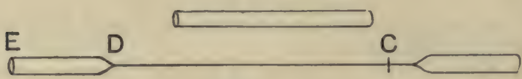


FIG. 43.

make the pointer, draw out a piece of glass tubing into a capillary tube about 8 in. long, break it off at C and, holding ED horizontal, apply heat to D. DC becomes vertical.

What is the result of the whole experiment? How is it that the invisible expansion has been made visible?

56. TO MEASURE THE EXPANSION OF SOLIDS.—The apparatus just described is not sufficiently accurate for quantitative results. One of its weak points is the unequal heating of the rod. It is essential that the rod should be equally heated from end to end, and that its temperature should be known. This is generally

managed by surrounding it first with ice or ice-cold water and next with steam, using the jacket of a Liebig's condenser for the purpose. A metal tube is sometimes used instead of a rod, and in this case the ice-cold water and steam can be passed through it.

Again, the measurement of a very small quantity requires great care and the use of special apparatus.

There are three methods in ordinary practice for measuring such small quantities.

(*a*) A microscope is used to magnify the movement.

(*b*) A screw gauge is used. This consists of a screw the pitch of whose thread is generally 1 mm. The screw head is enlarged and subdivided into 100 or more parts. If the screw head is turned round once the point of the screw moves through 1 mm. If the screw head is turned round $\frac{1}{100}$ of a turn, the point of the screw only moves $\frac{1}{100}$ of 1 mm. In this way very small distances, such, for instance, as the thickness of this sheet of paper, can be measured accurately.

(*c*) The end of the rod presses, by means of a pointer, against a light pivoted rod. If the portion of the rod below the pivot is twenty-four times that of the distance between the pointer and the pivot, then the distance moved by A along the scale will be twenty-four times that of the end of the rod.

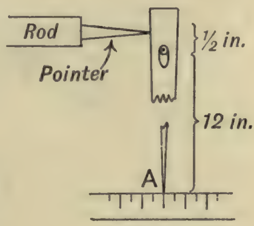


FIG. 44.

As a rule, the apparatus for measuring the expansion of a rod will be found already fitted up. Use that available and find the expansion of 1 cm. of brass or iron when heated 1° C. Failing this, the following may be tried.

57. *To determine the expansion of* 1 *cm. of brass when its temperature is raised* 1° *C.*

A rod of brass is passed through the jacket of a Liebig's condenser which is so fixed that one end of the rod is pressed against a block of wood upon which is a heavy

weight, and the other end is pointed and presses against a light rod moving on a pivot just below the point pressed upon by the rod.

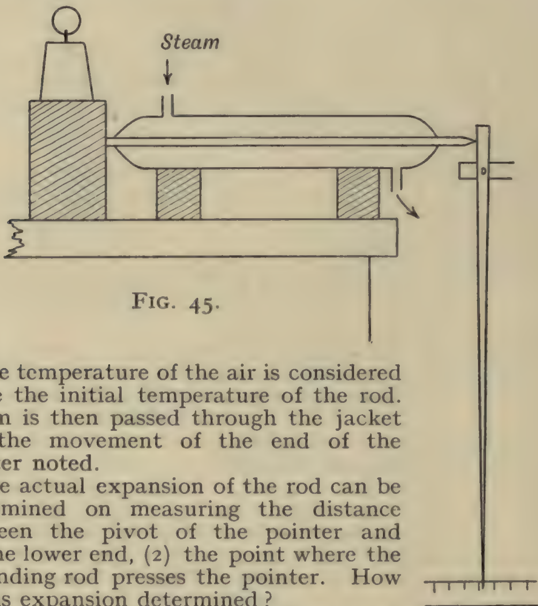


FIG. 45.

The temperature of the air is considered to be the initial temperature of the rod. Steam is then passed through the jacket and the movement of the end of the pointer noted.

The actual expansion of the rod can be determined on measuring the distance between the pivot of the pointer and (1) the lower end, (2) the point where the expanding rod presses the pointer. How is this expansion determined?

A knowledge of the initial length of the brass rod will enable you to calculate the expansion of 1 cm. of the rod when heated 1° C.

MATHEMATICAL EXERCISES—XI.

1. A rod of iron 120 cm. long when heated from 15° C. to 80° C. expanded ·093 cm. Calculate the expansion of 1 cm. of iron when heated 1° C.

2. A brass tube is 160 cm. long when ice-cold water is flowing through it, but 160·31 cm. long when steam is passing through it. Calculate the coefficient of linear expansion of brass.

3. Determine the expansion of 1 cm. of copper when heated 1° C. from the following results—

Length of copper bar . .	= 100 cm.
Initial temperature . . .	= 15° C.
Final temperature . . .	= 95° C.
Expansion	= ·132 cm.

4. A glass rod, 80 cm. long, increases in length ·056 cm. when heated from 14° C. to 98° C. What is the coefficient of expansion of glass?

5. A zinc tube increases from 90 cm. to 90·17 cm. in length when heated from 12° C. to 96° C. Calculate the coefficient of expansion of zinc.

58. SUPERFICIAL AND VOLUMINAL EXPANSION.—The expansion we have just been considering in the case of the brass rod is the expansion in length, that is linear expansion. **The expansion of 1 unit length of a rod when heated 1° is known as the coefficient of linear expansion.**

The expansion of a flat plate of metal or other material is sometimes required. It is known as superficial expansion. The expansion of 1 sq. cm. (or inch) of a surface when heated 1° C. (or F.) is called the coefficient of superficial expansion.

In a similar way we have often to consider the coefficient of voluminal (or cubical) expansion. Give the definition of this coefficient.

Having found one of these coefficients experimentally, it is not necessary to find the others for the same material, for the three are simply connected.

To determine the connection between the coefficients of linear and superficial expansion.

Suppose the line A B represents a bar of unit length (say 1 cm.) and that when the substance of which it is composed is heated 1° C. it expands a small amount represented by α. This length will be the coefficient of linear expansion.

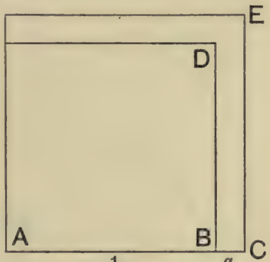


FIG. 46.

The square on A B, 1 sq. cm., represents the area of a plate at 0° C. The square on A C represents the area of the same plate at 1° C. The difference between these two

areas will be the increase in size of unit area when heated 1° C., *i. e.* it will represent the coefficient of superficial expansion.

$$\begin{aligned} \text{The square AD} &= 1 \text{ sq. cm.} \\ \text{,, \quad ,, \quad AE} &= (1 + a)^2 \text{ sq. cm.} \\ &= 1 + 2a + a^2 \text{ sq. cm.} \end{aligned}$$

The coefficient of linear expansion (a) is always a very small quantity, generally commencing with four or five noughts after the decimal point; hence a^2 will commence with eight or nine noughts and may therefore be neglected. The square on AE therefore becomes approximately equal to $1 + 2a$, which gives $2a$ as the coefficient of superficial expansion.

Thus the coefficient of superficial expansion is twice that of linear expansion.

Prove in a similar way that the coefficient of voluminal expansion is three times that of linear expansion.

59. The Force exerted by an Expanding or Contracting Body.—When a body expands it exerts force. The expansion of steam drives a steam engine. The force exerted by an iron bar expanding on heating, may be shown by the following experiment.

An iron rod I rests in grooves in the metal blocks BB which are parts of the solid metal casting BCB. Near

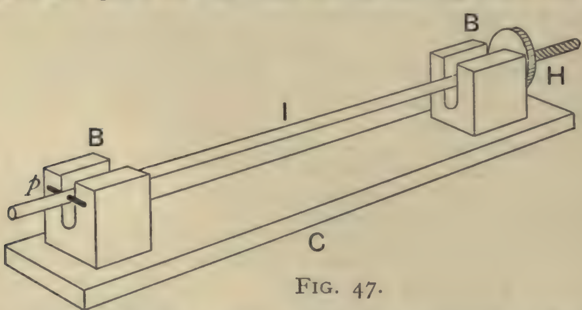


Fig. 47.

one end of the rod a hole is drilled of diameter sufficient to allow the passage of a cast iron pin p. At the other end a screw has been cut on the rod, and by means of the

screw head H the rod can be screwed up tightly between the two blocks BB. When the rod is heated by means of one or two bunsen burners it of course expands and becomes loose. While it is still hot screw up H. Continue screwing up until the rod ceases to expand and then remove the bunsens. The rod now contracts on cooling and the force on the pin p increases, becoming greater as the rod gets cooler, until eventually the pin breaks in two.

Wheelwrights take advantage of this great force of contraction when making cart wheels. The diameter of the iron tyre is made slightly smaller than the diameter of the wooden frame of the wheel, and in order to make it large enough to slip on it has to be heated. The rim is pushed on hot and water is thrown over it. This prevents undue burning of the woodwork and hastens the contraction, which latter binds the wheel very tightly together, making its diameter slightly smaller than it was before the iron rim was fixed.

Engineers have always to make provision for this expansion in designing metal structures. When laying railway lines a space of about half an inch is left between the end of one rail and the next to allow for expansion, otherwise the results would be disastrous. Bridges, too, require freedom of movement. In the 1700 ft. span of the Forth Bridge the rails are free to slide between 1 and 2 ft. With small iron girders in schoolrooms the expansion has been thought to be too insignificant to make provision for. In such a case the expansion and contraction of one or two years generally causes innumerable cracks in the plaster at the ends of the girders.

In America they are fond of making the framework of houses and skyscrapers of iron. Under ordinary conditions the expansion and contraction of this iron framework in summer and winter are too small to be specially allowed for, but if a fire breaks out the result is very disastrous and the expanding ironwork bends, twists, and crumples in its usually successful efforts to dislodge masonry.

In the riveting together of steel plates the rivets are put in and hammered up while hot. On cooling they contract and draw the plates very tightly together.

Many of you may have noticed the arrangement that connects the levers in railway signal boxes with the points. A is the end of the rod at the pointsman's lever, and D is the end at the points. If AD were continuous the points would move with variations of temperature although A remained constant. The rod is, therefore, broken at B and connected up as in the sketch.

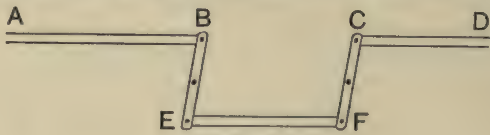


FIG. 48.

When the rods AB, CD, EF expand, A and D remain fixed.

60. UNEQUAL EXPANSION OF METALS.—All metals do not expand to the same extent when heated. Solder or rivet two equal lengths of iron and copper or iron and brass together and then gently heat the compound strip by passing it through the flame of a bunsen burner. It will bend owing to one metal (copper or brass) expanding more than the other (iron). How do you know which has the greater expansion?

Below is given a table showing the coefficients of linear expansion for various substances.

Glass	0·00000833
Platinum	0·00000899
Iron	0·0000119
Gold	0·0000139
Copper	0·0000168
Brass	0·0000189
Zinc	0·0000263
Steel	0·000011

The expansions of glass and platinum are very near each other, so that they expand and contract at approximately the same rate. It is on this account that whenever a metallic connection has to be made through glass,

platinum is used. The fact is especially useful in the making of electric lamps. The air is drawn out so that the glowing filament will not lose heat by convection and conduction, and as two air-tight metallic connections have to be made through the glass, platinum is used. Other metals will not do because they contract more than glass and therefore would not make an air-tight joint.

61. THE PENDULUM. — In summer a clock usually loses while it gains in winter. This gaining or losing has evidently something to do with the pendulum, because its adjustment puts the clock right. Let us make some experiments with a pendulum.

1. Suspend a weight by means of a thread the other end of which is clamped firmly. Be careful about the point of suspension—it is important. Set this simple pendulum swinging so that it moves always in the same plane and then find the time of a "to and fro" motion, *i.e.* of one vibration.

The best way to do this is to put a chalk mark on the floor so that the "bob" crosses it in its swing. Count whole vibrations—that is, each time the bob crosses the line in the same direction. Put down the time from a seconds ticking watch or clock, every ten vibrations, thus—

No. of vibrations	0	10	20	30	40	50	60	70	80	90
Time in seconds	4	17	30	43	56	9	22	35	48	61

Now by taking the time at 0 from the time of 50 we get an observation of the time of 50 vibrations. By taking the time at 10 from the time at 60 we again get the time of 50 vibrations, and so on. Take the average of the 5 times of 50 vibrations and from it find the time of 1 vibration. This method gives it very accurately.

FIG. 49.

2. *Find whether the amplitude affects the time of vibration.*

The amplitude of a vibration is the distance from the

middle point to the outside of the swing. Keep the length of the pendulum and the weight of the bob constant, and take the time of vibration for various amplitudes. Note the result.

3. *Does the weight of the bob affect the time of swing?*

Keep the length of the pendulum constant and measure the time of vibration, altering the weight of the bob each time.

4. *The effect of altering the length of the pendulum.*

You will have found in 3 and 4 that neither the weight of the bob nor the amplitude of swing (if not too large) has any effect on the time of vibration. We need not therefore trouble ourselves further about these. Let us turn our attention to the length.

Alter the length gradually from 10 cm. to about 140 cm. taking the times carefully as in 1. Plot L and T where L = length of pendulum from point of support to centre of bob and T = time of 1 vibration. Then plot L and T^2 on the same graph paper. What relation exists between the length and time of oscillation of a pendulum?

62. Effect of Rise of Temperature on the Time of Vibration.—After your experiments on the effect of increasing the length of a pendulum you will now probably know what effect an increase of temperature will have on the time of vibration. Clocks depend upon their pendulums for their time. In summer time when the temperature rises the pendulum expands, and therefore the time of swing becomes greater. The clock then loses. In winter the fall in temperature causes contraction and as the time of swing is shorter the clock gains. When a clock gains it may be restored to the usual rate of running by unscrewing the bob to make the pendulum longer. If the clock loses the bob should be lifted by screwing up.

63. Compensated Pendulums.—In order to prevent the rate of a clock changing, due to variation of temperature, compensated pendulums may be used.

The most common form of compensated pendulum is Harrison's Gridiron Pendulum. It consists of steel and brass bars arranged so that the steel expands downwards and the brass rods expand upwards (see Fig. 50).

The steel rods are S, the brass *b*. When the central steel rod supporting the bob expands it does so downwards because it is fixed at the top. The bob, however, does not get lower because the two brass rods supporting the central steel one expand upwards. The outside steel rods again expand downwards. It is quite evident that if the expansion of the brass rods upwards is equal to the expansion of the steel bars downwards, the bob will always be the same distance from the point of suspension. Hence the time of vibration will be constant whatever the temperature.

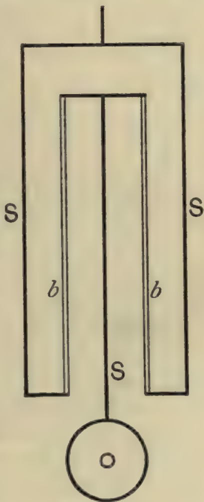


FIG. 50.

Example.

Find the length of a rod of brass which would expand the same amount as an iron rod 3 ft. long under a change of temperature of 10° C.

Let x = the required length.

1 ft. of brass heated 1° C. expands ·0000189 ft.

$\therefore x$ „ „ 10° C. „ $\cdot 0000189 \times 10 \times x$ ft.

1 ft. of iron heated 1° C. expands ·0000119 ft.

3 „ „ 10° C. „ $\cdot 0000119 \times 10 \times 3$.

Expansion of brass = Expansion of iron.

$$x \times 10 \times \cdot 0000189 = 3 \times 10 \times \cdot 0000119.$$

$$\therefore \quad x \times 189 = 3 \times 119$$

$$x \times 27 = 3 \times 17$$

$$x = \frac{3 \times 17}{27} = 1\cdot\dot{8} \text{ ft.}$$

Answer $1\cdot\dot{8}$ ft.

64. COMPENSATED BALANCE WHEEL.—Every one knows that a watch contains a balance wheel which controls the rate at which the watch goes. If the time of vibration of the balance wheel increases, the watch

loses, and vice versa. The balance wheel is, therefore, a very important part of a watch or chronometer.

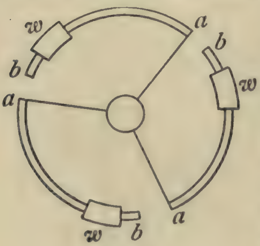


FIG. 51.

Now it can be shown by experiment that increasing the distance of the rim from the spindle or axle increases the time of vibration, just as increasing the length of a pendulum increases the time of vibration. In hot weather, therefore, a watch will lose and it will gain in winter. To prevent this, the best chronometers are provided with compensated balance wheels in which the rim is divided into three parts, *ab*, *ab*, *ab*. Each part *ab* is a "compound strip," the metal with the biggest expansion being outside. When the temperature rises the spokes expand, pushing out *a*, but the compound strip bends inwards so that the weight remains at practically the same distance from the spindle. The time of oscillation of the balance wheel is therefore unaffected.

65. "INVAR."—In 1897 M. Guillaume discovered an alloy composed of iron and nickel which has a negligible coefficient of expansion. The proportion of nickel in the steel is approximately 36 per cent. On account of its extremely small expansion the alloy has been called "Invar"—the first two syllables of invariable. Many clock pendulums and chronometer balance wheels are now made of "Invar."

QUESTIONS AND PROBLEMS—VIII.

1. Why do the telegraph wires along the railway side sag more in summer than in winter?

2. Explain how it is that a glass stopper is loosened if the neck of the bottle is heated. What happens (1) if

the heating is kept on too long, (2) if the heating is done too quickly?

3. Describe exactly what would happen if some boiling water is poured into a wine or beer bottle.

4. Why is it possible to boil water in a thin beaker without cracking it?

5. Why, when taking a railway journey, do the telegraph wires appears to move up and down the window? Is this up and down motion greater in summer or in winter? Why?

6. A hot metal ring is pushed tightly on a cold glass tube. What happens when the ring cools?

7. Why does the handle of a dinner-knife frequently break when the blade is put into boiling water?

8. What is a fire balloon? How does it act?

9. A thick piece of paper is held in front of the fire. Why does it curl towards the fire?

10. A flask of air inverted in a vessel of water, as in the diagram, is sometimes used as a barometer. Explain how it acts. What disadvantages has it?

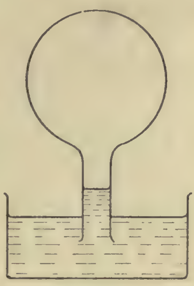


FIG. 52.

11. How are the junctions of hot water pipes made watertight, both when hot and cold?

12. The metal platinum is very expensive yet it is used in making electric lamps. Look up the coefficients of expansion of the materials of the lamp and then explain why platinum is used. Remember that the lamps contain no air and must be air-tight.

13. A careless dentist filled a tooth with a metal whose coefficient of expansion was greater than that of the tooth itself. What will be the results of his carelessness?

14. Clocks are often seen carrying two small jars of mercury in the place of the pendulum bob. Explain their purpose.

15. Explain as fully as possible why a hot piece of glass often cracks when a cold piece of metal touches it.

16. Explain why the height of the barometer must be corrected for temperature when an accurate reading is desired.

17. How is it that a clock which keeps good time in summer will not do so in winter? Will it gain or lose in winter?

18. A clock is found to be losing time. Should you lengthen or shorten its pendulum?

Mathematical Exercises—XII.

1. A zinc rod is 500 cm. long at 20° C. How much does it increase in length when heated to 150° C.?

2. Steel rails each 25 ft. long are laid at a temperature of 20° C. What space must be left between consecutive rails if they are likely to reach 40° C. during the year?

3. A brass rod measures 100 cm. at 0° C. What will be its length at (1) 15° C., (2) 50° C., (3) 100° C.?

4. An iron plate is 10 cm. wide and 25 cm. long at 0° C. What is its area at (*a*) 20° C., (*b*) 60° C.?

5. A pane of glass is 110 cm. long and 82 cm. wide at 15° C. What is its length, width, and area at 80° C.?

6. A copper sphere has a diameter of 3 cm. at 0° C. What will be its volume at 50° C.? The volume of a sphere $= \frac{4}{3}\pi r^3$.

7. Calculate the volume of a copper cube at 100° C. whose side at 15° is 1·7 cm.

8. The coefficient of expansion of zinc per degree centigrade is ·0000263. What would it be per degree Fahrenheit?

9. An iron rod is 120 cm. long at 0° C. and 120·145 cm. long at 100° C. Determine the coefficient of expansion of iron.

10. A brass bar is 100 cm. long at 0° C. At what temperature will it be 100·5 cm. long?

11. What length of iron will expand as much as 80 cm. of brass when heated through the same range of temperature?

12. A gridiron pendulum was made of 50 in. of iron and a length of brass. What was this length?

13. An iron tank is 4 ft. long, 2 ft. wide and 3 ft. deep at 0° C. How many cubic feet of boiling water will it hold?

Mathematical Exercises—XIII.

1. The steel rails of a railway are 8 yds. long. What space must be left between the rails to allow of a rise of temperature of 35° F.? The coefficient of linear expansion of steel is ·000011 per degree centigrade.

2. A steel yard measure is correct at 0° C. What is its error when placed in steam?

3. A brass cube of 2 cm. sides at 0° C. is placed in steam. What is then its volume?

*4. A barometer is correctly graduated at 0° C. What will be the correct barometric height at 20° C. if the barometer reads 75 cm.? Correct the height both for the expansion of the mercury and for the expansion of the brass scale.

5. A glass flask holds 250 c.c. at 15° C. What will it hold at 95° C.?

6. A mass of gold weighing 60·14 gm. has a volume of 3·1 c.c. at 0° C. What is its density (*i. e.* its mass per c.c.) at 0° C. and at 100° C.?

7. Taking the coefficients of iron and brass from the tables on p. 74, find the length of the iron bars of a Harrison gridiron pendulum if the length of each brass bar is 33 cm. Assume the pendulum consists of four equal brass and five equal iron bars.

SECTION IV

EVAPORATION AND CONDENSATION

66. The Effect of Heat on Water.—A beaker of water containing a thermometer is placed over a lighted bunsen.

Note exactly what occurs as the heat from the flame passes into the water—that the water "sings"; that bubbles form at the bottom and sides and rise to the top, getting larger as they rise; that some bubbles form at the bottom, and rise, getting smaller as they do so, and frequently disappearing before reaching the top; that later on some of these bubbles do reach the top producing steam; that steam has appeared to come from the top of the water before this. Note carefully the temperature at which each of these things occurs and try to explain the cause of each. When is the water said to boil?

Boiling is the process in which the bubbles of vapour formed near the bottom of a liquid rise up and burst through the surface.

Does the thermometer behave in the same way after boiling commences as it did before?

The boiling point of any liquid is the temperature at which that liquid boils as defined above. Place the thermometer in the steam just above the boiling water. Does it register the same as when it was in the liquid?

During the whole time of heating, heat is being transferred from the bunsen to the water; what changes has the heat produced previous to boiling? For what purpose is the heat utilised after boiling has commenced?

67. Do all Liquids have the Same Boiling Point?—Water is a common substance and we frequently use

more of it than we need. With other substances we must be more economical. Hence for this experiment fit up a small flask or large tube with a cork, through which passes a thermometer and safety tube. Place some methylated spirit in the flask but not sufficient to reach the thermometer. Heat the flask and note the temperature at which the spirit boils. Is it the same as that of water? Repeat the experiment with any other liquids that may be handy.

FIG. 53.

Different liquids have different boiling points, and liquids can often be identified by their boiling points.

*68. BOILING AND PRESSURE. — We have already seen that the temperature at which water boils depends upon the pressure to which it is subjected. The boiling point of a liquid is the temperature at which it boils when the barometric pressure is 76 cm. Refer back to § 31 and re-read what is said there on the subject and then perform the following experiment to show how the pressure and the corresponding temperature of boiling are related.

Fit up the apparatus illustrated in the diagram (fig. 54).

A is a round-bottomed flask fixed on a stand so that the water in it may be readily heated.

B is a Liebig's condenser so that no steam may reach the tube C or the pump.

C is a glass tube about 80 cm. long dipping into a basin of mercury.

All joints must be tightly wired so as to be thoroughly air-tight. To test this, partly exhaust the air in the apparatus by means of the pump. The mercury will rise in C; if its level remains steady the joints are all air-tight. When all is perfect raise the temperature of A, then exhaust the apparatus until boiling commences.

At the same time note (1) the temperature at which the water is boiling, and (2) the height to which the mercury has risen up the tube C above the level of the mercury in

the basin. The difference between this height and that of the barometer will give the pressure inside the apparatus.

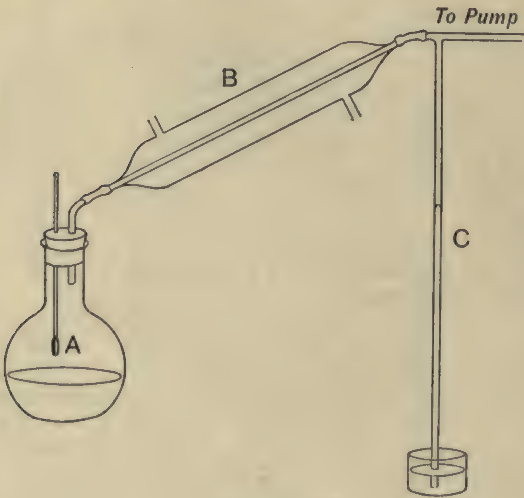


FIG. 54.

Repeat this again and again as the vessel A cools, tabulating the boiling point and corresponding pressure. Construct a graph from your results.

69. THE HEATING OF SEA WATER.—Find the boiling point of sea water in the same way as you have found that of other liquids. Is the temperature of the steam at the boiling point the same as that of the boiling liquid itself? If not, can you suggest any reason for it?

Heat some sea water in a beaker; describe exactly what happens and compare the results with those noted in the heating of ordinary water. When the water is nearly boiled away transfer it to a porcelain basin and continue the heating. What is the cause of the "spitting" that takes place when the water has nearly all disappeared?

What substance is tossed out of the basin during the "spitting"? What is left when all the water is boiled away? Taste it; does it taste exactly like ordinary salt?

We have now been able to get the salt out of sea water, but we have lost the water itself. We must next try to find out a way of recovering the water. If a cold vessel such as a plate is held in the steam from a kettle, what happens? Will any other object do as well?

Cooling the steam has condensed it into water.

Condensation is the change of a vapour, such as steam, back again to the liquid form.

Evaporation is the change of the liquid into the vapour.

Both occur at the temperature known as the boiling point.

70. DISTILLATION OF WATER.—**Distillation is the process of evaporation followed by that of condensation.**

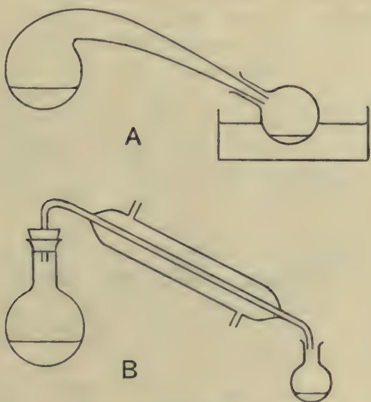


FIG. 55.

Distil some sea water by using one of the pieces of apparatus indicated in the diagram.

A is the simplest. It consists of a retort, containing sea water, with its neck fitted into a small flask floating on water to cool it.

B is more efficient. It consists of a flask and delivery tube joined to a Liebig's condenser.

Taste the water produced; it is called distilled water. Does it seem to contain salt? Find its boiling point and see whether the temperature of the steam is the same as that of the boiling water.

These experiments seem to show that when an impurity is present in a liquid, the temperature of the liquid when boiling is not the same as the boiling point; hence, to find the latter the bulb of the thermometer must always be placed in the vapour and not in the liquid.

The temperature of the liquid when boiling also depends somewhat upon the nature of the vessel it is in. This is another reason for having the bulb in the vapour.

71. HEAT.—In all these experiments something has passed from the bunsen into the vessels and liquid. The admission of the heat has caused the temperature to rise and the liquid to boil. If, while the temperature is rising, the bunsen be taken away, the rise ceases; hence we conclude that the rise in temperature is due to the heat which has passed from the bunsen to the liquid. Similarly the boiling ceases with the removal of the bunsen, and therefore the boiling must be maintained by the heat from the bunsen.

Note the difference between heat and temperature. **Heat is that something which has caused the rise in temperature.** Temperature is measured by means of a thermometer. Heat also can be measured and we must see later how this can be done.

72. HEAT OF VAPORISATION.—Most of the heat passing from the bunsen to the water was at first utilised by the liquid in raising its temperature. A little only was used in the production of steam. Later on, as soon as boiling commenced, the heat was used only in

evaporating the liquid. None of it was used in raising the temperature for the thermometer remained steady. The heat which is used up in keeping the water boiling is known as "heat of vaporisation." Some call it the "latent heat of vaporisation" since its presence seems to be hidden from the thermometer. The word "latent" means "hiding."

Let us try and get some idea as to how much this heat of vaporisation amounts to.

Weigh out a definite quantity of water in a flask and note the temperature. Place it over the lighted bunsen, which latter must not be altered after the experiment commences. Note carefully the time taken to bring the water to the boiling point. Continue heating the vessel for the same length of time after boiling, and then quickly plunge the vessel into cold water so as to stop all evaporation. Dry the outside and weigh it again so as to determine the amount of water boiled away.

Suppose that the following results were obtained—

Weight of water at first .	=	150 gm.
,, ,, end .	=	127 gm.
,, ,, boiled away	=	23 gm.
Temperature of water at first	=	15° C.

Then we see that the heat required to warm 150 gm. of water from 15° C. to 100° C. is the same as the heat required to boil away 23 gm. of hot water.

This does not, however, tell us how much heat was used.

73. THE UNIT OF HEAT.—The result of the last experiment cannot be stated more definitely as we have not yet learnt how to measure heat. When we wish to state the length of anything we have to use two terms. The first is a number, the second is called the unit. For instance, the length of a certain room is said to be "8 yards." This quantity consists of a number 8 and the unit called a "yard," which is the distance between two marks on a platinum bar kept in London. Similarly we have other units for ordinary quantities such as—ounce, bushel, mile, etc., all of which can be

easily understood. It is difficult, however, to conceive a unit which will apply to heat.

Heat, we have seen, is not the same as temperature. We know that it requires more heat to boil a gallon of water than it does a tumblerful, yet the thermometer would register the same in each. The amount of heat required to produce a given rise of temperature in a substance depends on the amount of substance you are using.

Our last experiment suggests a quantity which we can take as a unit. Let the unit quantity of heat be the quantity necessary to raise unit quantity of water through 1° in temperature. Since we have two sets of units in use, there will be two units of heat.

One set of units is the British one of feet and pounds with Fahrenheit graduations on the thermometers. **The British unit of heat will be the quantity of heat required to raise 1 lb. of water through 1° F**. It is called the "British thermal unit" (or the B.T.U.). This unit is used by engineers.

The other system of units is used by scientists and in most laboratories. It is called the metric or C.G.S. system, for the *c*entimetre, *g*ram and *s*econd are the units employed together with centigrade graduations on the thermometer. **The unit of heat** in this system **is the quantity of heat required to raise 1 gram of water 1° C.** It is sometimes called the **calorie.**

In the last experiment (§ 72), 150 gm. of water were heated from 15° C. to 100° C., that is, through 85° C.

Now—

1 gm. of water heated		1° C. requires	1 calorie of heat	
150 gm.	,, ,,	1° C. require	150 calories	,,
150 gm.	,, ,,	85° C. ,,	150 × 85	,,

But this quantity of heat was the same as that which caused 23 gm. of water to boil away.

The evaporation of 23 gm. of water required 150 × 85 calories of heat.

by evaporation of 1 gm. of water required $\frac{150 \times 85}{23}$
was us
soon as boil

$= 554$ calories.

The heat of vaporisation of water is the quantity of heat required to convert 1 gram of boiling water into steam, and is, according to this experiment, 554 calories.

Use the figures you got from your own experiment and determine the value of the latent heat of vaporisation of water. What is your result? What is the average result of the class?

74. CONDENSATION.—We have already seen that water in boiling uses up a quantity of heat which is not indicated on the thermometer. We have seen that steam can be condensed, that is, changed back again to water without any change of temperature. What, then, becomes of all that heat which was used up in converting water into steam?

An experiment to determine whether any heat is evolved during condensation.

Fit up a flask A with a good cork and delivery tube C bent in such a way that water condensed in C will run back into A. The delivery tube is connected to a piece of "lead" tubing (E) of the same width, which passes through a wide glass tube B capable of holding at least 100 c.c. of water.

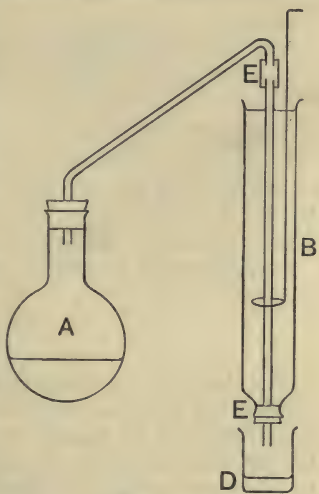


FIG. 56.

The water in A is boiled and the steam is allowed to pass through the apparatus until the whole is hot. The jacket B is then filled with a known quantity of water and at the same time the weighed beaker D is placed so as to catch the condensed steam. The vessel D is surrounded by a non-conducting substance so that little heat is lost. After a time the temperature of the water in D is noted and found to be nearly 100° C., so

that steam at 100° C. has been passed into E and water at 100° C. has issued from it. In the meantime the water in B has been getting hotter. It should be kept well stirred and the final temperature taken when D is removed for the purpose of weighing the water in it. The heat in B must have been given out during the condensation of the steam. We will call this heat the *heat of condensation*, and its value can be approximately determined from the results of the above experiment.

Results—

Weight of beaker	= 33·5 gm.
Weight of beaker and condensed steam	= 41·0 gm.
Initial temperature of water in B .	= 18° C.
Final ,, ,, ,, .	= 57° C.
Weight of water in B	= 100 gm.

Owing to the condensation of (41 − 33·5) = 7·5 gm. of steam, 100 gm. of water were raised from 18° C. to 57° C., *i. e.* through 39° C. In this rise of temperature 100 × 39 = 3900 calories of heat were used up.

In condensing 7·5 gm. of steam 3900 cal. were given out.

$$\text{,,} \quad \text{,,} \quad 1 \quad \text{,,} \quad \text{,,} \quad \frac{3900}{7{\cdot}5} \quad \text{,,} \quad \text{,,}$$
$$= 520 \text{ cal.}$$

The heat of condensation is the heat given out in condensing 1 gm. of steam at 100° C. to water at 100° C. It is found to be nearly 540 calories. This is virtually the same as the heat of vaporisation. Hence we come to this conclusion—that **the heat absorbed during boiling is given out again during condensation.**

MATHEMATICAL EXERCISES—XIV.

1. Steam is passed through a jacketed tube surrounded by 115 gm. of water which is thereby raised from 20° C. to 62° C. The water condensed was at 100° C. and weighed 8·5 gm. What value does this give for the (latent) heat of condensation?

2. A flask containing 250 gm. of water at 15° C. took 9·5 min. to boil. After boiling for 15 min. it was found that 188 gm. of water remained in the flask. What amount of heat was rendered latent in boiling away 1 gm. of water?

3. A flask holding 250 gm. of water at 15° C. took 11 min. to boil. Boiling was then continued for another 11 min., after which the flask was quickly cooled and weighed. It now contained 210 gm. of water. Calculate the amount of heat absorbed during the boiling away of 1 gm. of water.

75. To Determine the Heat of Vaporisation.—Both the methods just employed for finding the heat of vaporisation (or condensation) are incapable of giving exact results. Try to find out some of the sources of error in each.

In the first experiment we assumed that the heat given out by the bunsen was constant throughout the whole experiment and that a constant portion of it passed into the water. Was it so?

In the second experiment we assumed that all the heat given out during condensation was passed into the water jacket, and that the latter received no heat from the cooling of the water produced. Was this the case? Can you detect any other sources of error?

In the next experiment we will try to avoid any errors such as those above.

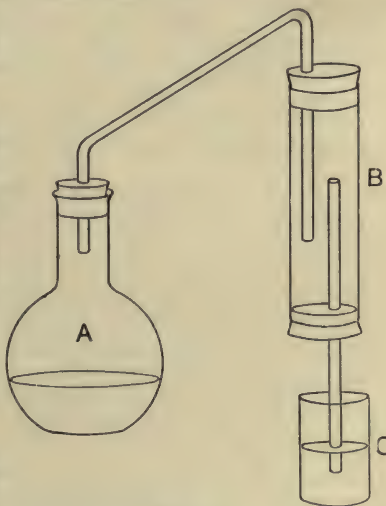


Fig. 57.

The purpose of this experiment is to find out how much heat is given out during the condensation of 1 gm. of steam at 100° C. into water at 100° C.

Steam is produced in the flask A and passed through a delivery tube into cold water in the vessel C. Here con-

densation occurs and the heat evolved warms up the water. The advantage of this method is that less steam is likely to pass through uncondensed. Some condensation may occur, however, in the delivery tube and the hot water produced will drop into C and warm it. This must be prevented; hence the tube B is inserted and any hot water produced will be stopped from entering C. How does B act?

In performing the experiment boil the water in A and as soon as the steam is passing freely through the tube place it in the water in the vessel C. C contains a fairly large quantity of water, the weight of which is accurately known. Stop the passage of the steam into C as soon as any steam appears to be coming from the top of the water, *i. e.* as soon as the temperature reaches 50° C. Note this temperature exactly. Notice that all the readings are in connection with the beaker C and its contents. Tabulate your results as follows—

Weight of beaker	=	20 gm.
Weight of beaker and cold water .	=	220 gm.
,, ,, ,, hot ,, .	=	232 gm.
,, steam passed into beaker .	=	12 gm.
Temperature of cold water . .	=	15° C.
,, ,, hot ,, . . .	=	50° C.

In making the calculation we must remember that the main point of difference between this and the last experiment is that the final temperature of the condensed steam is not 100° C. but 50° C.

Two hundred grams of water were heated through 35° C.; this required $200 \times 35 = 7000$ units of heat (calories).

These were obtained from the condensation of 12 gm. of steam and the cooling of the condensed steam to 50° C.

The cooling of the 12 gm. of boiling water to water at 50° C. gave out $12 \times 50 = 600$ units of heat. Therefore only $7000 - 600$ units were obtained by the condensation of the 12 gm. of steam. One gram of steam in condensing to water at the same temperature

produced $\frac{6400}{12} = 533$ calories. This, then, is the heat of vaporisation.

If in class work several results are obtained, take the average of them and enter it in your notes as the class average. Is the class average nearer the truth than your own result?

In the metric or C.G.S. system the (latent) heat of vaporisation of water is 537 calories per gram.

In the British system the (latent) heat of vaporisation is 967 B.T.U. per pound.

Mathematical Exercises—XV.

1. How much heat will be given out in cooling 20 gm. of water at 100° C. to water at 20° C.?
2. How much heat will be given out in converting 20 gm. of steam at 100° C. into water at 100° C.?
3. How much heat will be given out in converting 20 gm. of steam at 100° C. into water at 20° C.?
4. Why is it so much more painful and so much more serious to be scalded by steam than by boiling water?
5. What amount of heat is required to raise 100 gm. of water from 10° C. to 30° C.?
6. Three hundred units of heat were put into 120 gm. of water at 20° C. What temperature was attained?
7. What amount of heat is required to raise 10 gm. of water to the boiling point and to boil it all away?
8. A thousand units of heat are transferred to 10 gm. of water at 20° C. What would be the result?

Questions and Problems—IX.

1. If the water in a thick iron kettle is boiled and the kettle is then removed from the fire, does the water continue to boil? Why?
2. What is happening when the kettle begins to "sing"?
3. Suggest some reasons why distilled water is not so pleasant to drink as ordinary tap water.
4. Is it possible to boil water in a paper cup? Give reasons for your answer.
5. At the top of Mont Blanc water boils at 185° F. Explain why this is.
6. Why does it take a long time to cook potatoes at the top of a mountain such as Mont Blanc?

76. THE TRANSFER OF HEAT.—When two bodies, not at the same temperature, are brought into contact, heat passes from one to the other until the temperatures of both are alike. The heat will, of course, pass from the one of higher to the one of lower temperature and the final temperature will be intermediate between the two.

Add 50 gm. of hot water at 55° C. to 50 gm. of cold water at 15° C. and note the temperature of the mixture. It will be about 35° C.

(*a*) 50 gm. of hot water have changed from 55° to 35° C. and have lost $50 \times 20 = 1000$ calories.
(*b*) 50 gm. of cold water have changed from 15° C. to 35° C. and have gained $50 \times 20 = 1000$ calories.

The heat lost by the one has been gained by the other. We have assumed this principle in previous work and it can now be assumed in all following work.

Accurate experimental results can, however, only be obtained if all gains and losses of heat are carefully accounted for.

Test the accuracy of the above principle by mixing—

(*a*) 20 gm. of cold water with 50 gm. of hot and noting the heat lost or gained in each case.
(*b*) Repeat with other quantities.

77. MATHEMATICAL CALCULATIONS.—The calculations given in this section can be somewhat simplified as under—

A. Twelve gm. of steam are passed into 200 gm. of water at 15° C., thereby raising the temperature to 50° C. Calculate the heat of vaporisation.

Heat gained by cold water = Heat lost by steam in condensing and cooling.

$$(200 \times 35) = (12 \times X) + (12 \times 50)$$

where X = all the unknown heat of vaporisation.

$$7000 = 12X + 600$$
$$12X = 7000 - 600$$
$$X = \frac{6400}{12} = 533 \text{ cal.}$$

B. Fifty grams of hot water at 60° are mixed with some cold water at 10° C. The temperature of the mixture was 45° C. What quantity of cold water was used?

Let X = the quantity of cold water used, then—

$$\text{Heat lost by hot water} = \text{Heat gained by cold water}$$
$$50 \times 15 = X \times 35$$
$$X = \frac{50 \times 15}{35} = 21{\cdot}4 \text{ gm.}$$

C. One hundred grams of boiling water are mixed with 45 gm. of ice-cold water. What is the temperature of the mixture?

Let X = the unknown temperature which must be between 100° C. and 0° C.

$$\text{Heat lost by hot water} = \text{Heat gained by cold water}$$
$$100 \times (100 - X) = 45 \times (X - 0)$$
$$10000 - 100X = 45X$$
$$145X = 100000$$
$$X = 69° \text{ C. nearly.}$$

Mathematical Exercises—XVI.

1. What quantity of heat will be required to boil away 3 gm. of water at 100° C.?
2. A vessel of water weighed 27·3 gm. After boiling for five minutes it was found to weigh only 20·2 gm. How much heat had passed into the water per minute?
3. How much heat will be required (1) to raise 20 gm. of ice-cold water to the boiling point; (2) to boil it all away?
4. Five hundred units of heat are passed into 10 gm. of water at 100° C. What weight of water is boiled away?
5. How much heat will be required to evaporate *m* gm. of a liquid without changing its temperature, the (latent) heat of evaporation being L?
6. Calculate the (latent) heat of vaporisation of water in each of the following cases—
   (*a*) Six grams of steam at 100° C. on being passed into 120 gm. of water at 10° C. raised the temperature to 40° C.
   (*b*) Sixteen grams of steam at 100° C. are passed into 500 gm. of water, thereby raising its temperature from 15° C. to 34° C.
   (*c*) By passing 20 gm. of steam at 100° C. into 350 gm. of ice-cold water the temperature of the latter is raised to 34° C.

(*d*) One hundred grams of ice-cold water are raised 82° C. by passing 15 gm. of steam into them.

7. Into 50 gm. of water at 10° C. 3 gm. of steam are passed. To what temperature is the water raised?

8. What rise of temperature takes place when 10 gm. of steam are passed into 200 gm. of water at 15° C.?

9. Ten pounds of water at 0° C. are mixed with 1 lb. of steam at 100° C. What is the resulting temperature?

10. How many grams of steam must be passed into 100 gm. of water at 15° C. in order to raise the temperature to 30° C.? Would double the quantity be required to raise the temperature to 45° C.? If not, how much steam would be required?

11. Steam at 100° C. is passed into 260 gm. of water at 0° C. till the temperature reached is 50° C. What was the weight of the water at the end of the experiment?

12. X grams of steam at 100° C. are passed into y gm. of water at 0° C. What was the temperature of the mixture?

13. a gm. of steam at 100° C. are mixed with b gm. of water at C° C. What is the temperature of the mixture?

78. Evaporation.—We are perfectly familiar with many cases of the conversion of water into vapour without any boiling taking place. A rain-puddle in the street soon dries up, so also do the flagstones after a shower. Wet clothes hung out by the washerwoman quickly get dry. These things occur although the temperature may be very low. This change is quite different from the changes which we have hitherto been considering in which water is converted into steam at a perfectly definite temperature called its boiling point. As we see from the above examples evaporation is an almost invisible change while the change called boiling is always visible.

We must now consider these changes. In the cold winter days, when the streets are covered with ice and the rooftops with snow, when the sun is invisible but the air is crisp and dry, we shall find the snow and ice slowly disappearing. Evaporation is taking place although the temperature is below freezing point.

Evaporation can take place at all temperatures, but

the rate at which it occurs varies very much from time to time. We have all noticed how quickly the streets dry up on some days and how slowly on others.

79. Upon what Conditions does the Rate of Evaporation Depend?

1. Does it depend upon the temperature? Into each of two evaporating basins place a known weight of water. Keep one at 35° C. and the other at 60° C. Find out from which basin the water has evaporated more quickly.
2. Does it depend upon the movement of the air around? Into each of two similar evaporating basins place a known weight of water. Keep each at the same temperature. By means of a fan or bicycle pump blow a stream of air over one but not over the other. Find out from which basin the water is evaporating more quickly.
3. Does it depend upon the surface exposed? Use a wide and a narrow evaporating basin and determine whether the evaporation is as quick from the one as from the other.
4. Does it depend on the amount of moisture already in the air? Take two similar basins containing equal quantities of water and keeping both at the same temperature allow evaporation to take place in the open room in one case and in an enclosed space in the other. What result do you notice?

The results of these experiments will show upon what the rate of evaporation depends.

1. The higher the temperature of the liquid and the warmer the air around it the greater the evaporation. The air immediately above the liquid gets warmed and, as we shall find later, the warm air holds more moisture than it does at a lower temperature.
2. It is greater the greater the rapidity with which the air above the liquid is changed. Since it is

the air that takes up the vapour, the more quickly it is changed the less likely it is to become saturated, *i. e.* filled with water vapour and unable to take up more.

3. The greater the extent of surface exposed to the air the greater the rate of evaporation.
4. The rate of evaporation decreases as the air around gets more and more saturated. In an enclosed space the air, being confined, quickly becomes saturated with moisture and hence will not assist evaporation.

*80. THE AMOUNT OF MOISTURE IN THE AIR.—We all know that bodies dry more quickly in summer than in winter—on hot days than on cold days. Hot air seems capable of taking up more moisture than cold air. Does it, however, contain more moisture when saturated?

Air is said to be saturated when it contains as much moisture as it will hold—that is, when it has been in contact with the liquid for some time.

To find out whether warm saturated air contains more moisture than cold saturated air.

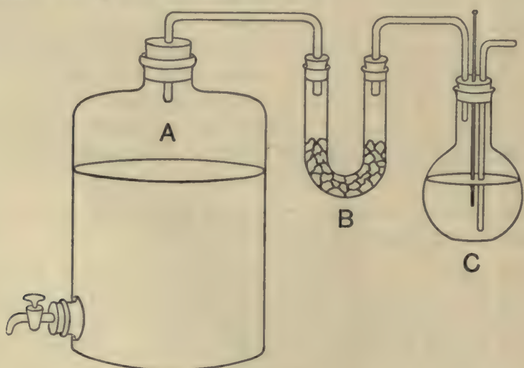


FIG. 58.

Fit up the apparatus shown in the sketch. It consists of a large two-gallon jar filled with water and attached

to a U-tube containing pumice stone soaked in sulphuric acid. The other limb of the U-tube is connected with a flask fitted with delivery tubes and thermometer.

See that all the fittings are perfectly air-tight so that when the tap is turned on and water runs out from A, air is drawn through B, which contains a dehydrating agent, *i. e.* one which absorbs all the moisture passing near it. The air is saturated by being drawn through the water in C. The amount of air being drawn through is measured by the water passing from A. The amount of moisture in this air is measured by the difference in the weight of B before and after the experiment.

Repeat the experiment, the water in C being raised to about 50° C., and from your results determine whether equal quantities of saturated air at different temperatures contain the same amount of moisture.

81. HEAT ABSORBED DURING EVAPORATION.—Let the fingers be moistened and held in a draught or moved about quickly. What do you notice?

Place some ether on the hands, observe how quickly it dries up and how cold it makes the hands feel. Is it the ether or the water that is cold? You can easily find this out by using a thermometer. The ether is not colder than the air around and yet it makes the hand feel very cold—so cold, indeed, that it often feels as if the hand will freeze. Try the following experiment.

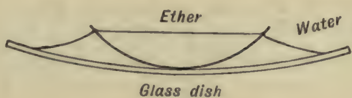


FIG. 59.

Obtain a very thin metal cup and fill it with ether. Place it on a glass dish with a small quantity of water between as in the diagram. Blow over the ether so as to make it evaporate quickly. The water will probably freeze and fix the cup to the dish.

We know that in order to make water boil it has to be supplied with heat. If the heat supply ceases

then the boiling ceases. This heat we call the heat of vaporisation. In exactly the same way heat is required for evaporation although the quantity needed by any particular substance is not the same when boiling as when merely evaporating.

If the heat required for evaporation is not supplied the evaporating liquid will take it from surrounding substances which thereby will be considerably cooled. Walking about in your wet bathing clothes in the bright sunlight is not dangerous since the sun is supplying the heat required for evaporation. Doing the same thing, however, when the sun's supply is cut off by clouds will generally produce a cold since the body has to supply the heat required. It is safer never to remain in damp clothes at any time.

*82. Refrigerators.—These are machines for the production of cold. In many cases the lowering of the temperature is brought about by the rapid evaporation of some liquid. A liquid of low boiling point is chosen, for it will then be cold to commence with. Liquid ammonia is a favourite substance; so also is liquid carbon dioxide.

The diagram (Fig. 60) illustrates a type of machine in which ammonia gas is first liquefied and then allowed to evaporate rapidly so as to produce the cold required. Starting from right to left, an engine works a pump which compresses the gas to a very small bulk. This compressed gas will now liquefy as it passes through tubes kept cold in a cooling tank. The liquid is stored until required, a small portion only at a time being allowed to enter the coils where it evaporates. As these coils are large and the pressure in them is small the evaporation is very quick and great cold is produced. The low temperature produced by such an arrangement as is described is used for cold storage of meat, vegetables and fruits.

In other cases the evaporating coils are surrounded by brine which is thereby cooled and is used for ice making, for making ice cream and for other purposes.

The cold brine is passed through pipes similar to radiators which, of course, cool the chamber instead of heating it.

83. Cold Storage. — Food turns bad because it is attacked by certain germs (bacteria). These germs are killed at a high temperature. Below 50° F. the germs are inactive—that is, they cease attacking the food. Above 170° F. they are destroyed, hence the need for cooking most articles of food before using them.

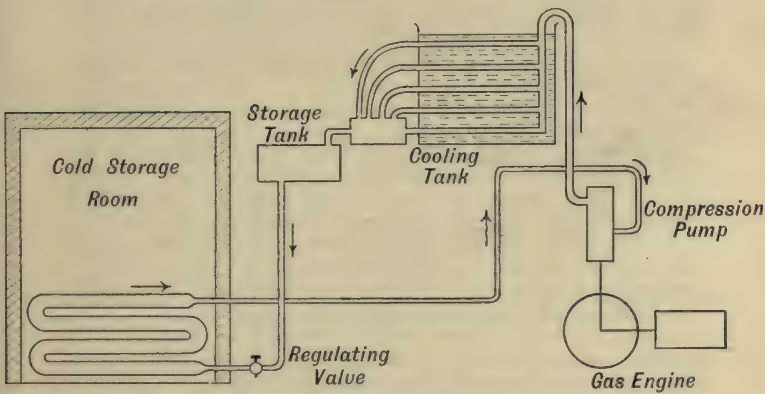


Fig. 60.

Cold storage is becoming more and more employed, for in consequence of it shiploads of food stuffs can be brought over here whenever the fruit is sufficiently ripe or when the cattle are in prime condition for killing. The food stuffs can then be kept in refrigerating chambers till required, or until there is no longer a glut on the market and better prices are obtainable.

*84. Liquid and Solid Air.—When air is subjected to great pressure and cooled to −130° C. (= − 202° F.) it liquefies. If liquid air be allowed to suddenly evaporate the cold produced is sufficient to freeze some of the

remaining liquid. In this way we can obtain solid air. Under ordinary pressure liquid air boils at about $-190°$ C.

Questions and Problems—X.

1. Explain why a man wets his finger in order to determine the direction of the wind.
2. Will clothes dry if hung out when it is freezing?
3. A thermometer bulb is covered with wet muslin. Will it make any difference to the temperature registered? Why?
4. Why do clothes dry more quickly if the wind is blowing them about?
5. Dry air causes water to evaporate more quickly than moist air does. Why is this?
6. In hot countries water is cooled by exposing it in the shade in shallow vessels made of porous materials. Explain why shallow vessels are used, why a porous material is employed, and why the exposure is made in the shade.
7. Why does one feel colder if, after washing, a towel is not used for drying the face and hands?
8. Why does water evaporate more rapidly when the wind is blowing than when it is calm?
9. Butter is often kept cool in summer by placing it in a vessel enclosed in a porous pot which contains water. Why does this arrangement cool the butter?
10. What sort of walls would be best for a cold storage chamber?
11. A draught of cold air is best for keeping fruit in a cold storage room. Suggest a way in which it may be obtained.
12. Describe and explain the various ways in which a hot cup of tea may be cooled.

Condensation of Atmospheric Vapour.

85. **What becomes of the Water Vapour in the Air?**—Returning once again to the consideration of the evaporation of water into the air, we are struck by the fact that such evaporation is going on all around us and yet the air seldom seems to be full of vapour.

Sometimes in winter the air is moist and clothes hung out to dry fail to do so; but for the greater part of the year the air seems capable of taking up an unlimited supply of moisture. What becomes of it all? This is the next question for us to consider.

Although the air extends all round the earth for a depth of fifty miles or more, yet there is not enough of it to retain all the vapour. It does not do so, for if it did the surface of the earth would quickly dry up. In India's hot and sultry dry season, when the monsoons blow from land to sea, evaporation is very rapid, and in many parts not only are little streams and ponds dried up, but large rivers and lakes also. This would happen all the world over if the air had an unlimited capacity for absorbing moisture.

That the return of the moisture takes place we know, for even in this country it rains, though we do not often appreciate the blessing of it.

In India, when the monsoon blows from sea to land the moisture-laden winds give up their rain, the lakes are filled and the rivers flow again. The whole land puts on a new garb and seems to flourish once more, for the lost moisture has returned again in the form of rain.

86. Moisture and Clouds.—We must now trace the changes that the moisture undergoes before it returns to the earth.

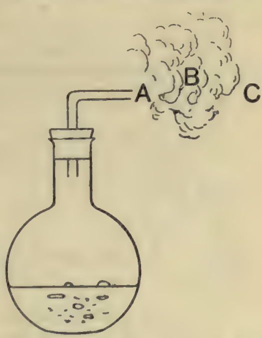


Fig. 61.

Fit up a flask with cork and wide delivery tube as in the diagram. Boil the water in it and note the steam coming from the spout. There are three distinct parts. Near the tube at A the steam is invisible; a little further off at B it forms a cloud, and further away still at C this cloud seems to roll about and then melt away into the air. In the first condition the vapour is so hot that the air is not saturated. Further on the air and vapour

cool, the space becomes saturated and drops of moisture are formed, producing a cloud of steam. Still further off the clouds roll about and come into a region of air which is not saturated with moisture. The cloud drops are then absorbed and disappear.

This is just what happens in the atmosphere. The vapour rising into the air is insufficient to saturate it, especially on a warm day, and the vapour remains invisible.

The vapour spreads higher and higher and is wafted about by the winds or directed upwards by the presence of high lands, until at last it reaches a part where the air is readily saturated and a cloud is formed. Very frequently if you sit on a hill-side towards the close of a hot summer's day you will see the clouds form in the midst of a clear blue sky. The change from the invisible vapour to the visible cloud is brought about by a reduction of temperature.

*87. To show the Effect of a Reduction of Temperature on Saturated Moist Air.

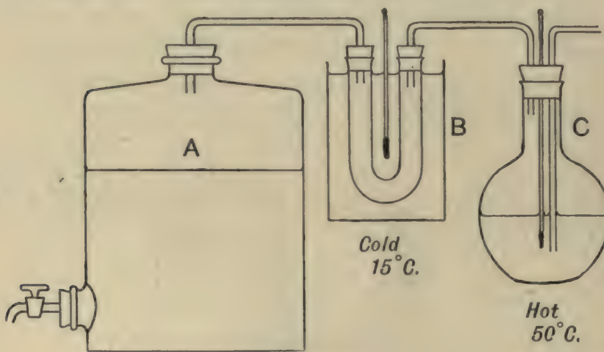


Fig. 62.

The apparatus shown in the sketch can be fitted up. By means of it air is drawn through hot (50° C.) water in C, and saturated with moisture, and then through a clean dry U-tube surrounded by cold water at about 15° C.

What happens in the U-tube? It has been caused by the reduction in temperature.

When the drops of water produced in the air are very small they form a cloud.

88. The Reduction of Temperature in the Upper Air.—This is brought about in various ways.

1. The higher one goes in the air the colder it gets. The sun is the chief source of heat, but the sun's rays pass through the air without heating it. It is not till they reach the earth that they become heating rays. For this reason it is much warmer in an enclosed valley than on an open plain.

2. Winds are currents of air, sometimes warm and sometimes cold. Hence with winds blowing in different directions a cold current may lie above a warm one, or vice versa. Look up into the sky on several successive days and notice whether you ever see the clouds in the upper parts of the air moving in a different direction from those in the lower parts.

3. When one rises up into the air there is a gradual reduction of pressure (see § 22). When the pressure acting on a body of air is reduced, the volume increases according to Boyle's *Law* (see §§ 39–41). Now try the following experiments—

(*a*) Use a bicycle pump to inflate your tire and note how hot the nozzle gets. Air when compressed gets heated.

(*b*) Allow the compressed air to cool and then let it escape. Place a thermometer in the escaping air and note how cold it is. Air when expanding becomes cooled.

When a current of air is deflected upwards by the presence of mountains or other high land it is cooled by its own expansion.

Exercise.—Fill in the missing words in the following sentences—

(*a*) When moving *up* a mountain side the pressure of the air becomes . . . .
(*b*) When the pressure *decreases* the volume of the air becomes . . . .
(*c*) When the volume *increases* the temperature is . . . .
(*d*) When the temperature is *lowered* the vapour in the air becomes . . . .

Now alter each word in italics to one having the opposite meaning and again complete each sentence. Alter the form of (*d*) to suit the new train of ideas.

89. Kinds of Clouds.—Clouds are divided into (*a*) cirrus, (*b*) cumulus, (*c*) stratus, and (*d*) nimbus clouds, according to their appearance.

Cirrus clouds are formed at great heights — usually several miles. They are probably made of minute ice crystals, for the air at that height must be at an extremely low temperature. Their appearance is that of fine feathery flakes at a great altitude.

Cumulus clouds reach about a mile up and have the appearance of massive white rounded accumulations. They are usually seen on a summer day with bright blue sky above, and are formed by ascending currents of saturated air.

Stratus and nimbus clouds are the lowest. The former appear in layers, hence their name. It is probable that they mark the junction of layers of air of different temperature moving in different directions. The cold layer condenses the moisture in the saturated warmer layer at their common surface. They are often seen at sunset.

Nimbus clouds are the heavy black overhanging storm clouds which mean certain rain for the land beneath.

Clouds on hill tops often appear to be stationary when, as a matter of fact, the particles of water composing them may be continually changing. A stream of saturated air passing over the cold top of a hill would give rise to a stationary cloud. Can you give reasons for this?

FIG. 63.—Clouds.

90. THE FORMATION OF RAIN.—With a reduction in the temperature of the air we see that clouds form from the vapour. With a continued reduction new particles are not formed, but the older ones get larger and at last fall as rain. The presence of dust particles assists the formation of drops both large and small so much that there will be very little condensation in the absence of the dust—even clouds will not form easily.

91. THE RAIN GAUGE.—The amount of rain that falls on a given area is measured by means of an instrument called the rain gauge. In its common form it consists of a copper funnel of either 5 in. or 8 in. diameter inserted in a copper bottle, both being surrounded by a jacket which is firmly pegged to the ground. This latter precaution will prevent it from being blown over by the wind or knocked over by straying animals. The instrument must be set up in an open space away from houses, trees, walls and suchlike which might deflect the rain. The rain is measured by being poured into a measuring jar which holds half an inch of rain. That is to say, it holds sufficient rain to cover a circle of 5 in. or 8 in. with water half an inch deep. The measure is graduated to read $\frac{1}{10}$ and $\frac{1}{100}$ in.

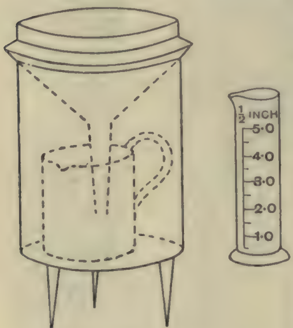


FIG. 64.

92. REGIONS OF GREAT RAINFALL.—Regions of great rainfall are places where moisture-bearing winds are deflected upwards either by (*a*) mountains or (*b*) convection currents due to heat. Such regions occur (*a*) near the Western Ghats of India and near the Khassia Hills in Eastern Bengal where the south-west monsoons come filled with moisture from over the sea, or (*b*) near the equator where the hot air rises in con-

vection currents which carry upwards the moisture-laden winds from the sea and so cool them.

The greatest rainfall in the British Isles occurs in the Snowdon district of North Wales.

93. Snow, Hail and Sleet.—These are formed when the temperature reduction is very great. When the small cloud drops are frozen they crystallise in most beautiful patterns, and a number of them joining together form a snowflake which falls more or less slowly to the ground.

Should these snowflakes pass through a warmer region on their way to the earth they are in part melted and a mixture of snow and rain, called sleet, falls. The sleet is in the process of thawing, and, as we shall find later on, it is absorbing heat. The weather, consequently, feels cold and disagreeable.

Should, however, the raindrops form before they reach the cold region of the air they will be frozen into hail as they pass through it. Hail frequently accompanies a thunderstorm when also the drops of rain are much larger than usual.

94. Mist and Fog.—When in a mist we are really in the middle of a cloud. Mountaineers frequently have the experience of starting a climb in fine weather, then a mist arrives—really they climb into a cloud—and lastly they finish the climb in clear, bright sunshine with the clouds rolling beneath them.

Clouds form at all heights from the surface level to seven miles or so above it. Those near the surface form mists in which the deposit of moisture has taken place upon dust particles.

When the dust particles are extremely numerous, as frequently occurs in or near large cities, then a fog is formed.

Questions and Problems—XI.

1. Clothes dry quickly in a room heated by hot water or steam pipes. Why is this? Suggest how a large steam laundry may dry the clothes quickly.

2. Will ice dry up? What are the conditions, if any?

3. In rooms heated by steam pipes throats become parched. Why is this so?

4. What is the difference between a fog and a cloud?

5. Clothes are not hung out to dry in a fog. Why is this?

6. What determines whether the water vapour in the air returns to the earth as hail, snow, sleet or rain?

7. To dry a photographic plate quickly you are recommended to hold it in spirit for a short time, then to wave it about near the fire or hot water pipes. Explain the reasons for this.

8. Why does a kettle boil sooner when the lid is on than when it is off?

9. Why does water evaporate more rapidly from a shallow pan than from a bottle?

10. Why does water evaporate more rapidly when the temperature is high than when it is low?

11. An enamelled iron vessel containing ice becomes surrounded by a pool of water. The vessel does not leak, how then comes the water there?

12. Why does the dentist make his small mirror warm before placing it in your mouth to look at the back of your teeth?

13. In winter time the pretty ice patterns, "Jack Frost's pictures," are on the inside of the windows. Explain their formation there.

14. Explain how it is that the steam from the funnel of a locomotive is invisible when near the funnel but further away forms a visible cloud and then again seems to melt away into the air.

15. There is a space between the steam cloud and the end of the pipe from which it issues. Is this space of the same size in winter as in summer?

16. Give any reasons you can think of to explain why it is that few clouds occur higher than seven miles from the earth.

17. Describe the appearances known as (*a*) mare's tail, (*b*) mackerel sky, (*c*) rain cloud, (*d*) scud.

18. There is generally a north wind, if any, blowing in Egypt. Why do the clouds disappear as they approach that country?

19. Which variety of cloud would you call "the day cloud"? Give your reasons.

20. Clouds often form just before sunset, growing denser as darkness comes on but disappearing soon after sunrise. Describe the appearance of these clouds.

SECTION V*

ATMOSPHERIC MOISTURE AND HYGROMETRY

Atmospheric Moisture.

95. The Quantity of Moisture in the Air.—When dealing with evaporation we noted the enormous quantities of water which are constantly passing into the air and falling again as rain. The large amount of moisture that falls as rain even in this country is hardly realised. For instance, Greater London covers an area of 692 sq. m. Its rainfall is 24 in. per year. This means that if the water did not run away it would cover the whole district 24 in. deep in one year. It is quite easy to find the weight of this water, for we know that 1 in. of rain means 4·673 gal. or 46·73 lb. of water per square yard. This is 101 tons per acre. The total weight of water falling in one year on London averages nearly 45,000,000 tons.

It is important that we should have some knowledge of the laws that govern this moisture in the atmosphere. We already know how it came there—wafted by the wind from over the sea or evaporated from wet ground, lake or river. We know that if the quantity it contains is greater than it is capable of holding it will fall as rain or snow.

96. The Weather Prophet.—In the days of our grandfathers people often used a little household instrument to let them know whether rain was probable or not. It was called the "Weather Prophet," and consisted of a small model house with two doors, from one of which a man came out if the weather was likely to

be wet, and a woman from the other if fine weather was predicted. The man and woman were fixed to a slightly stretched hair which curled up if the air was moist and uncurled if the air was dry. The coiling and uncoiling moved the man and woman respectively.

A piece of gingerbread or a piece of seaweed acts very similarly, getting soft in damp weather and hard in dry weather. Try one of these, hanging it up outside the window.

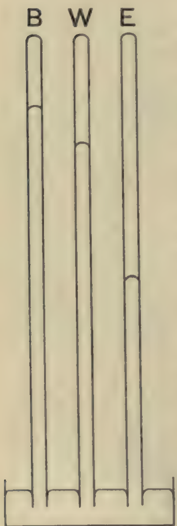


FIG. 65.

The confidence reposed in these "instruments" by our forefathers was very great. They were easy to understand and easy to read. They are not, however, suited to a more scientific age when greater accuracy is looked for. In the present age an exact numerical statement of the quantity of moisture in the air is necessary, and this can be obtained from a knowledge of the vapour pressure.

97. VAPOUR PRESSURE.—Fit up three barometer tubes filled with mercury as in the making of barometers. The mercury should be at the same height in each. Use the one marked B as a reference tube.

By means of a bent pipette introduce water drop by drop into the tube marked W, noting the effect produced by each drop as it is added. Each will be seen to rise to the surface of the mercury and then disappear into the vacuum, the mercury being forced down. The water vapour must have exerted some pressure to do this—a pressure which we call the vapour pressure of water and which is measured by the difference in height of the mercury columns B and W. The addition of each drop of water will increase the amount

of vapour in the Torricellian vacuum, for each drop disappears on reaching it, causing a further depression of mercury. The vapour pressure exerted thus depends upon the amount of vapour present.

At last, however, there comes a time when the addition of another drop is not followed by its disappearance in the vacuum, and consequently is not accompanied by an increase in the vapour pressure. The space in the "vacuum" has become saturated. A space is saturated with a vapour when the vapour is in contact with its own liquid. No further addition of liquid will increase either the amount of vapour or the vapour pressure. It only adds to the amount of liquid above the mercury.

These experiments are somewhat difficult to do with water, but if ether or alcohol be used instead, the results are very clear. The pressure exerted by the ether vapour when saturated is much greater than the pressure of the water vapour. The vapour pressure depends, then, on the liquid that is being experimented with.

Let us now in some way reduce the size of the vacuum either by depressing the mercury tube in the basin or by tilting it to one side. In the latter case the heights measured must be measured vertically. We shall see that if the space is saturated reducing the volume of the vacuum does not alter the pressure, it only increases the amount of liquid. In the same way increasing the size of the vacuum decreases the amount of liquid, but does not alter the pressure.

This shows that to saturate a space with vapour the amount of substance that has to be used depends on the size of the space, but the pressure exerted by the saturated vapour is always the same, no matter what is the size of the space. Remember that we have previously shown that prior to saturation the pressure does depend on the amount of vapour present, but it is not so after saturation. When speaking of vapour pressure we generally mean that of the saturated vapour unless it is otherwise stated.

Repeat these experiments carefully and note down the conditions that affect the vapour pressure. The conditions that affect the pressure of saturated vapour are easy to determine; not so those affecting unsaturated vapours.

98. *To show that prior to saturation the pressure depends upon the amount of vapour present per unit of space.*—Fit up a Boyle's Law apparatus as in the diagram. The rubber connecting tube should be at least 60 cm. long. To the tap at the top, wire on a good piece of pressure tubing A fitted with a glass stopper. Fill the tube A with alcohol and insert the stopper, taking care that there are no air bubbles.

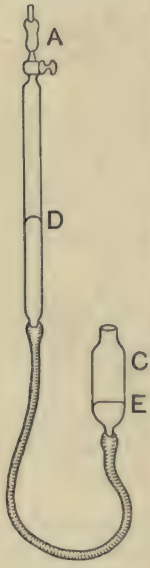


Fig. 66.

Fill the apparatus with mercury and lower the reservoir C until the whole acts as a barometer of the siphon pattern.

Open and quickly close the tap at A. This will introduce a small quantity of alcohol into the vacuum. Note the volume of the vapour and the pressure to which it is subjected, *i. e.* the difference of level between D and E. The difference between this pressure and that of the barometer will give the pressure exerted by the vapour.

Raise the reservoir C and re-read volume and pressure. Suppose the results are as follow—

1. When no vapour was present the volume of the vacuum was 5 cm. The difference between the levels D and E of the mercury was 76 cm., which, therefore, was the barometric height.
2. When x grams of alcohol were introduced—

Volume of vapour.	Difference between D and E.	Vapour pressure.	Mass of vapour present in unit volume.
cm.	cm.	cm.	
24·9	74·9	$76 - 74{\cdot}9 = 1{\cdot}1$	$\frac{x}{24{\cdot}9} = {\cdot}04x$
16·6	74·35	$76 - 74{\cdot}35 = 1{\cdot}65$	$\frac{x}{16{\cdot}6} = {\cdot}06x$
12·45	73·8	$76 - 73{\cdot}8 = 2{\cdot}2$	$\frac{x}{12{\cdot}45} = {\cdot}08x$
8·3	72·7	$76 - 72{\cdot}7 = 3{\cdot}3$	$\frac{x}{8{\cdot}3} = {\cdot}12x$

From the figures in columns 3 and 4 it is clear that **the vapour pressure is proportional to the mass of vapour present per unit of volume.**

FIG. 67.

99. VAPOUR PRESSURE AND TEMPERATURE.—*Is the vapour pressure affected by a change in temperature?*

Fit up a barometer as before and introduce a liquid into the vacuum so as to saturate the space. Surround the upper part of the barometer tube with a wider tube and fill the latter with water. By means of this water jacket we can vary the temperature of the space containing the vapour. Note the temperature of the jacket and the corresponding vapour pressure. Raise the temperature of the jacket by blowing a small quantity of steam through it. Allow time for the temperature to get constant throughout and then note it and the corresponding vapour pressure. Repeat this again and again. Does the vapour pressure vary with the temperature?

As the vapour pressure gets larger the size of the "vacuum" also increases and so also will the amount of vapour necessary to saturate it. Hence, as

the experiment proceeds, see that there is sufficient liquid present in the barometer tube to keep the " vacuum " saturated.

When the temperature is very high remove the water jacket and replace it by a steam jacket which will entirely surround the whole barometer tube. Blow steam through so as to raise the temperature to 100° C. and note the vapour pressure. See that the space is saturated.

Repeat the experiment with ether and alcohol. Draw graphs to illustrate your results. From them we conclude that **the vapour pressure increases with the temperature,** and that at the boiling point of the liquid used the vapour pressure is equal to the barometric pressure for the time being.

This gives us a new definition of boiling point: **The boiling point of a liquid is that temperature at which its vapour pressure is equal to the atmospheric pressure.**

The vapour pressure of water at different temperatures has been accurately determined and the results can be referred to in future work.

Questions and Problems—XII.

1. The air contains some water vapour, but not sufficient to saturate it. What must I do in order to obtain it saturated? No more water must be used.

2. A barometer is fitted up so as to have a large vacuum. Water is introduced, but not sufficient to saturate the space. The vapour pressure is noted. The barometer is now inclined so that the volume of the space is reduced. Will the pressure of the vapour be altered. If so, why?

3. A barometer contains just sufficient water to saturate the space above the mercury. The temperature is raised; will the space still be saturated? Will the pressure be altered? Give reasons for your replies.

4. A long tube, as in the diagram, is inverted in a deep vessel of water. Will this make a satisfactory barometer? Give reasons for your reply.

Will it make a good thermo-barometer—that is, an instrument for measuring the combined effect of temperature and pressure upon a given volume of gas?

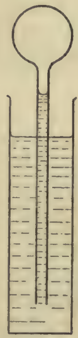


FIG. 68.

100. VAPOUR PRESSURE.—The two most important facts we have just learnt are—

1. The pressure of a saturated vapour is constant if the temperature is constant.
2. If the vapour be not saturated the pressure is less than when saturated and depends upon the amount of vapour present per unit volume. It does not depend upon the temperature so long as it remains unsaturated.

As has been previously stated, the pressure of the water vapour saturating a space has been accurately determined and tabulated. If we know the temperature we can consult these tables to find the pressure.

101. PRESSURE OF AQUEOUS VAPOUR.

Temp.	Pressure.	Temp.	Pressure.	Temp.	Pressure.
deg. C.	cm.	deg. C.	cm.	deg. C.	cm.
0	·46	11	·98	22	1·96
1	·49	12	1·04	23	2·09
2	·53	13	1·11	25	2·35
3	·57	14	1·19	30	3·15
4	·61	15	1·27	40	5·49
5	·65	16	1·35	50	9·20
6	·70	17	1·44	60	14·89
7	·75	18	1·53	70	23·33
8	·80	19	1·63	80	35·49
9	·85	20	1·74	90	52·55
10	·91	21	1·85	100	76·00

The pressure of an unsaturated vapour can be found by reducing the temperature, which does not alter the pressure, until it becomes saturated. Then, on noting the temperature at which saturation occurs, we can determine the pressure from tables as before.

Mathematical Exercises—XVII.

1. A space is just saturated with aqueous vapour at 20° C. What is the pressure of the vapour? If the temperature be now raised to 30° C. what is the vapour pressure?
2. Some air (which makes no difference to the vapour pressure) containing aqueous vapour at 20° C. is cooled till it is saturated. This occurs at 15° C. What was the pressure of the aqueous vapour when at 20° C.?
3. Some air is saturated with aqueous vapour at 25° C.; what is the vapour pressure? The temperature is now reduced to (1) 20° C., (2) 10° C. What is the vapour pressure in each case?

102. Dew Point.—**The temperature to which the air must be reduced so that the water vapour in it may be just sufficient to saturate it is known as the Dew Point.**

A knowledge of the dew point is very useful, as it enables us to find from tables the pressure of the vapour in the air, and this, we have seen above, is proportional to the amount of vapour present.

The usefulness of knowing how much water vapour there is present in the air is self-evident to most people. If we know it we can get some idea as to the probability of rain, information which is of use both to the farmer and the pleasure seeker.

The whole of this knowledge depends entirely upon our being able to determine the "dew point"—that is, the temperature at which the vapour present in the air will be deposited as moisture. To reach the dew

point the temperature of the air must be lowered, and we know that we have reached the dew point when we see the moisture begin to be deposited in the form of dew. A dew point instrument is, therefore, one which cools the air and shows the deposit of moisture. They are called hygrometers and there are several varieties of them.

103. Daniell's Hygrometer.—John Daniell was born in London in 1790. He became professor of chemistry at King's College, London, and invented his hygrometer in 1820. It consists of two exhausted bulbs containing ether and connected by a bent tube. In one bulb is a delicate thermometer, while another thermometer is fixed on the stand. Ether is poured on a piece of muslin around the bulb A. This ether evaporates.

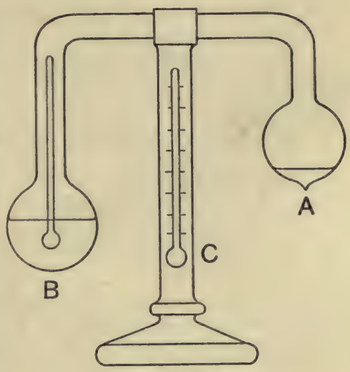


Fig. 69.

What is the effect on the bulb and on the ether vapour inside it? This effect causes a partial vacuum in the tube.

What is the effect of this on the ether in the bulb B?

How does the thermometer behave?

What will be the effect on the air around the bulb?

In order to show the presence of the condensed moisture (dew) the bulb B was formerly blackened. It is now often gilded.

The result obtained is stated thus: When the temperature of the air is that shown by C, dew becomes deposited on cooling the air down to the temperature shown by B.

Obtain a Daniell's hygrometer and determine the dew point of the room in which you are working.

Questions and Problems—XIII.

[The following questions refer to Daniell's hygrometer.]

1. The temperature of B steadily falls as the ether on A evaporates. The dew will not be seen until *after* the dew point is reached. Suggest some way of avoiding the error.

2. Can you point out any other errors that are likely with this instrument?

3. Why is muslin used round one of the bulbs?

4. Complete the following sentences with regard to this hygrometer—

   (*a*) The evaporation of the ether from the muslin causes the . . . of the vapour within the bulb.
   (*b*) The resulting vacuum produces the . . . of ether in the other bulb.
   (*c*) Evaporation is always accompanied by . . .
   (*d*) The steady cooling of ordinary air at last produces . . .

5. On one occasion dew was seen on the bulb when the temperature inside read 30° F. How do you account for the non-appearance of hoar frost?

104. Regnault's Improved Hygrometer.—Who was Regnault? What work of his are you already acquainted with? When did he live?

The evaporation of ether around the bulb of Daniell's hygrometer was considered to so alter the condition of the air that the deposit of moisture would take place earlier than it otherwise would.

To read Daniell's instrument the experimenter must be close to it, and his breath will be all the time increasing the moisture in the air. This would falsify the reading of the instrument.

To avoid these two sources of error Regnault devised his instrument. It consisted of a glass tube containing

ether through which air was drawn so as to increase the rate of evaporation. The deposit of moisture on the gilded surface could be seen clearly at a distance. To increase this readiness of view the bottom of the glass tube is sometimes replaced by a polished silver cap. Silver is a better conductor than glass; would this fact improve the instrument?

Can you suggest what the second similar glass tube is for?

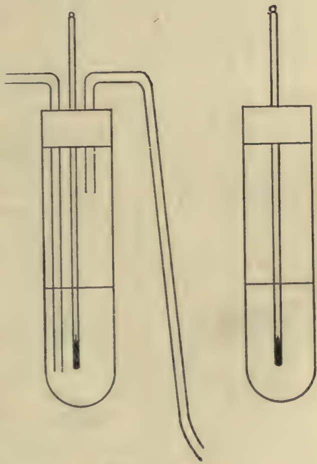


FIG. 70.

105. DINES' HYGROMETER.—This, like Daniell's and Regnault's hygrometers, is also one of the condensation type. The dew point is found by noting the temperature at which dew is formed.

The instrument consists of a rectangular reservoir to contain ice-cold water, which latter is slowly run under

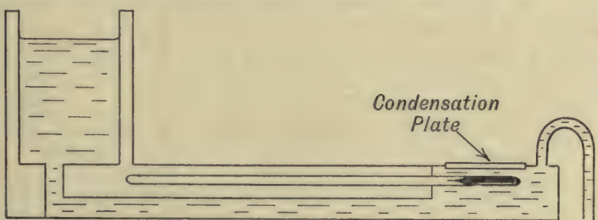


FIG. 71.

a blackened glass plate on the top of which the moisture will be deposited. The dew point is read by means of a thermometer, the bulb of which is below the plate.

An improved form has recently been brought out.

It is a vertical instrument and consists of a cold water reservoir (R) connected by a tube and tap with a chamber C, the front side of which is covered with darkened glass so as to show condensation. An outlet O is so arranged that the chamber remains filled. Should it be desired to pass ether through the chamber it can be admitted by a side tube E.

A thermometer has its bulb in the centre of C, the stem being in front of the reservoir R.

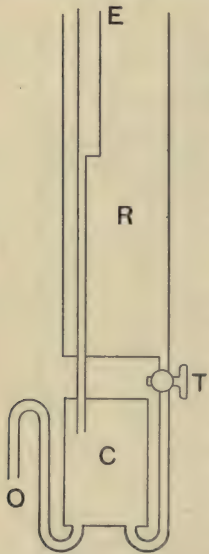


FIG. 72.

106. DE SAUSSURE'S HYGROMETER.—This is an instrument often used in North Russia and Scandinavia. It is better suited to cold countries. It is one of the absorption type. It consists of a single hair thoroughly cleansed from grease, suspended from a hook and kept taut by means of a weight. The thread attaching it to the weight passes round a pulley wheel fitted with an index pointer. The movement of the pointer indicates the lengthening or contraction of the hair, which lengthens as it absorbs moisture and contracts as it dries.

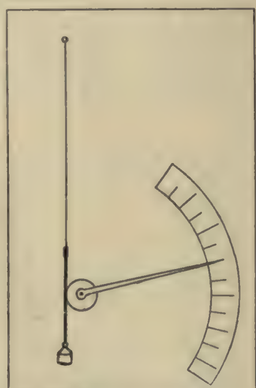


FIG. 73.

107. HOW THE QUANTITY OF MOISTURE IS STATED.—We have seen how to determine the dew point, but the mere statement that the dew point is 12° C. does not give us any immediate idea of the amount

of moisture in the air, nor does it give us any indication of the probability of rain. We know that if the air be saturated with moisture rain is very probable, and that if it contain a large proportion of moisture it is more likely to rain than if the proportion were small. This means that the nearer the dew point is to the temperature of the air, the more is it likely to rain.

This, however, is not sufficient. We should, in some way or other, be able to give the relation between the actual quantity of moisture in the air and the quantity necessary to saturate it. This relation is sometimes given as a fraction, when it is called the "relative humidity of the air," and sometimes as a percentage, when it is known as the "hygrometric state of the air."

The relative humidity of the atmosphere is the amount of moisture present in unit volume of the air compared with the amount necessary to saturate unit volume of dry air at the same temperature. Thus, if the relative humidity of the air is given as $\frac{4}{5}$, or ·8, it means that the air contains four-fiths of the moisture which it would hold if saturated.

The hygrometric state of the atmosphere is the amount of moisture present in unit volume, given as a percentage of the amount of moisture required to saturate the same volume of dry air. Thus, if the hygrometric state is given as 80 per cent., it means that the air contains 80 per cent. of the moisture which it would hold if saturated. It will be seen that—

$$\text{Relative humidity} \times 100 = \text{hygrometric state.}$$

108. Relative Humidity.—From the previous definition we see that relative humidity is equal to—

$$\frac{\text{Amount of moisture present in given volume}}{\text{Amount of moisture required to saturate the same volume of air}}.$$

The amount of moisture present is, however, proportional to the vapour pressure at the dew point, while

the amount required to saturate it is proportional to the vapour pressure at the temperature of the air.

Therefore the fraction becomes—

$$\frac{\text{Vapour pressure at the dew point}}{\text{Vapour pressure at the temperature of the air}}$$

both of which can be found from tables if the dew point is first found experimentally.

Determine by experiment the relative humidity and hygrometric state of the air of the room in which you are working.

The pressure of the aqueous vapour at varying temperatures can be found tabulated in § 101.

The relative humidity should not be less than ·5. When the room is heated by steam pipes, the relative humidity tends to get less than ·5. There will then be some appliance for supplying the further amount of moisture.

Questions and Problems—XIV.

1. Throughout a certain day the dew point remained at 9° C. The temperature at 9 a.m. was 12° C.; at 1 p.m 15° C.; while at 7 p.m. it fell to 11° C. How did the relative humidity alter during the day?

2. Air which has a low relative humidity is said to be "dry." Is the air at noon drier than at midnight, even if the amount of moisture is the same?

3. How do you account for the fact that the air is drier in summer than in winter although it contains a much larger quantity of moisture in summer than in winter?

109. The Wet and Dry Bulb Hygrometer.—The three hygrometers already mentioned will each give the dew point directly. This is their great advantage. On the other hand, some skill is required in performing the experiment, and it takes time.

In common everyday work most English people use

a hygrometer which is easy and quick to read, although it does not give the dew point directly. This is Mason's wet and dry bulb hygrometer. It consists of two thermometers hung side by side. The bulb of one is surrounded by muslin kept moist by absorbent tape dipping into a vessel of water placed below it.

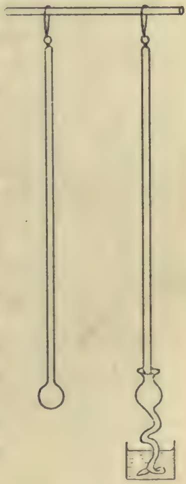


FIG. 74.

The wet bulb is surrounded by unsaturated air. What happens?

What is the effect of this upon the temperature of the wet bulb?

Upon what does the rate of its cooling depend?

What does the instrument indicate since it does not give the dew point?

Why would it give a false reading if the instrument is so placed that the wind, or a draught, blows upon it?

The wet bulb was on one occasion found to be much colder than the dry one. What does this indicate?

On a second day the two thermometers were found to be almost alike. What was the condition of the atmosphere? Which of the two would be the higher?

On another occasion the wet and dry bulbs are found to read alike. What information does this convey about the air?

Do you think that any circumstances are likely to arise which will cause the wet bulb to be warmer than the dry one?

110. To obtain the Dew Point by means of Mason's Hygrometer.—Fix up two thermometers not far from one another. Compare their readings and note that they are almost identical. Around the bulb of one wrap some muslin or wool and allow the ends to dip in water so as to keep them wet. After a few minutes take the

two readings. Suppose they are 16° C. for the dry, and 12° C. for the wet one. From these readings we have now to determine the dew point.

This question was first tackled by James Glaisher (1809–1903), who for many years was superintendent of the meteorological department at Greenwich observatory. He devoted much time to the study of atmospheric humidity, making many balloon ascents for the purpose. In 1862 he reached a height of seven miles. In 1885 he published his deductions. Among many other things he noted that the dew point was always below the reading of the wet bulb thermometer, but that it was not always at a constant distance below. It depended upon both the readings. He deduced a formula as follows—

(*a*) Take the two readings and note their difference.
(*b*) Multiply this difference by a factor which depends upon the temperature of the dry bulb.
(*c*) Subtract this product from the dry bulb reading. This will give the dew point.

111. Glaisher's Factors.

T.	Factor.	T.	Factor.	T.	Factor.	T.	Factor.
°F.		°F.		°F.		°F.	
32	3·32	42	2·23	52	2·02	62	1·86
33	3·01	43	2·20	53	2·00	63	1·85
34	2·77	44	2·18	54	1·98	64	1·83
35	2·600	45	2·16	55	1·96	65	1·82
36	2·50	46	2·14	56	1·94	66	1·81
37	2·42	47	2·12	57	1·92	67	1·80
38	2·36	48	2·10	58	1·90	68	1·79
39	2·32	49	2·08	59	1·89	69	1·78
40	2·29	50	2·06	60	1·81	70	1·77
41	2·26	51	2·04	61	1·87	71	1·76

T = Temp. of dry bulb in F. degrees.

Mathematical Exercises—XVIII.

1. The readings of the Mason's hygrometer on four successive days were—

(*a*)	Dry bulb	40° F.	Wet bulb	38° F.
(*b*)	,,	44° F.	,,	40° F.
(*c*)	,,	45° F.	,,	40° F.
(*d*)	,,	50° F.	,,	44° F.

Determine the dew point in each case.

2. The temperature of the air was one day noted as 64° F. when the dew point was 56° F. What would have been the reading of the wet bulb thermometer that day?

3. The dry bulb reading is 20° C., while that of the wet bulb is 15° C. What is the dew point?

4. In each of the above cases calculate the relative humidity of the air.

112. *To determine the hygrometric state of the air from the readings of a wet and dry bulb hygrometer.*

On considering the last question in the previous exercises we shall see that in determining the hygrometric state, two tables are required—

1. Glaisher's factors for finding dew points.
2. Regnault's vapour pressure tables.

These two have been combined into one table. It is given below. It gives the pressure of the aqueous

Temp. of dry bulb.	Difference between wet and dry bulbs.										
	0°.	1°.	2°.	3°.	4°.	5°.	6°.	7°.	8°.	9°.	10°.
° C.											
0	4·6	3·7	2·9	2·1	1·3						
2	5·3	4·4	3·6	2·7	1·9	1·1	0·3				
4	6·1	5·2	4·3	3·4	2·6	1·8	0·9				
6	7·0	6·0	5·1	4·2	3·3	2·4	1·6				
8	8·0	7·0	6·0	5·0	4·1	3·2	2·3	1·4	0·6		
10	9·2	8·1	7·0	6·0	5·0	4·0	3·1	2·2	1·3		
12	10·5	9·3	8·2	7·1	6·0	5·0	4·0	3·0	2·1	1·2	0·3
14	11·9	10·7	9·4	8·3	7·1	6·1	5·0	4·0	3·0	2·0	1·1
16	13·5	12·2	10·9	9·7	8·4	7·3	6·0	5·0	4·0	3·0	1·9

vapour in mm. of mercury at the dew point when the dry bulb reading is that of column one, and the difference between the two readings is that of the other columns.

Mathematical Exercises—XIX.

1. Determine the hygrometric state of the air when the temperature is 18° C. and the dew point 14° C.?
2. What is the relative humidity of the air when the temperature is 17° C. and the dew point is 11° C.?
3. The relative humidity of the air is ·3 when the temperature is 18° C. What is the dew point?
4. What is the hygrometric state when the readings of Mason's hygrometer are—

(*a*) 16° and 12° C.; (*b*) 16° and 10° C.;
(*c*) 15° and 9° C.; (*d*) 13° and 11° C.?

Mathematical Exercises—XX.

1. Determine the hygrometric state of the air in each of the following cases—

(*a*)	Temperature	of air	25° C.	Dew point	20° C.
(*b*)	,,	,,	25° C.	,,	15° C.
(*c*)	,,	,,	15° C.	,,	15° C.
(*d*)	,,	,,	15° C.	,,	10° C.
(*e*)	,,	,,	15° C.	,,	5° C.

2. What is the dew point when the dry bulb reads 20° C. and the wet bulb 16° C.?
3. The maximum pressure of aqueous vapour at 10° C. is 9·2 mm. of mercury, while at 20° C. it is 17·4 mm. of mercury. What is the relative humidity of the atmosphere if the dew point is 10° C. when the temperature of the air is 20° C.?
4. If the temperature of the air is 18° C. and the relative humidity ·5, what is the dew point?

5. Determine the relative humidity of the atmosphere when its temperature is 65° F. and its dew point 60° F.

6. From the following figures draw graphs to show the change in (1) the dry bulb readings; (2) the wet bulb readings; (3) the dew point; (4) the relative humidity.

Time	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 a.m.	1 p.m.	2 p.m.	3 p.m.
	Deg. C.	Deg. C.	Deg. C.	Deg. C.	Deg. C.	Deg. C.	Deg. C.	Deg. C.
Dry bulb	16	16·1	16·4	16·8	17·2	18	19	21
Wet bulb	15	15·1	15·25	15·5	15·7	16	16·3	16·7

Questions and Problems—XV.

1. A towel is hung in the open air. What conditions will determine whether it gets damp or dry?

2. Explain as fully as you can what is meant by the "wetness" of the air.

3. A day is sometimes said to be a good "drying" day. What is meant by this?

4. March winds are said to assist in bringing forth May flowers. How do they assist?

5. Watering a dusty road in summer-time produces a refreshing effect. Explain why this is.

6. Does dew fall? Explain your answer fully.

7. The air feels drier at midday than in the early morning although no rain or dew has been produced. Explain fully why this is so.

8. If the dew point rises between early morning and noon, rain will most probably follow. Explain why this is so.

9. Explain how it is that fine weather is probable when there is a great difference between the readings of the wet and dry bulb thermometers.

10. Owing to the drainage of land and the reclamation of wastes the mean temperature of this country is higher than it used to be. Explain the reasons for this.

11. The breathing of dry air is good for curing consumption. Where would you recommend a consumptive person to live in order to obtain the dry air?

12. "There are few climatic factors which influence our sensations more strongly than humidity." Illustrate this statement.

13. In the Kalahari Desert the dew point is often 14° C. below the temperature of the air. Is the climate dry?

14. "It will be wet to-day, the old man is out." Explain this.

15. What are the advantages and disadvantages of Mason's hygrometer compared with Daniell's?

16. What do you understand by hygrometric state? Explain how it is indicated numerically.

SECTION VI

FUSION AND SOLIDIFICATION

113. FREEZING AND SOLIDIFICATION. — In the last section we noted the change of cloud into snow and of rain into hail, a change in which a liquid becomes solid. This in the case of water is called freezing, in the case of other bodies it is called solidification. The opposite change of solid into liquid is called fusion.

We must now consider these changes more fully before we can really understand the formation of ice, snow, frost and hail, and their effect on their surroundings.

114. *Is there any similarity between fusion and vaporisation?*—Obtain some broken ice and note its temperature. Gradually warm it in a beaker and observe all the changes that take place. Does the temperature remain constant during the change as it does in the case of vaporisation? If it does, then there must be a heat of fusion, just as there is a heat of vaporisation. The heat of fusion is called by some the latent heat of fusion.

During fusion heat is absorbed. **The quantity of heat absorbed during the fusion of 1 gram of ice at 0° C. into water at 0° C. is called the heat of fusion.**

115. *To determine the heat of fusion of ice.* — Place about 100 gm. of slightly warmed water in a beaker, noting its exact weight and temperature. Add some

dry ice sufficient to bring its temperature down to about 10° C. Four or five pieces about the size of large nuts will do. Note the weight of the ice used (it will be the same as that of the water produced) and the final temperature immediately after the last piece of ice has dissolved. Tabulate your results as usual and calculate the heat of fusion as under—

Weight of water . .	= 100 gm. at 20° C.
Weight of water and ice	= 110 gm. at 11° C.

The water was cooled by the melting ice and gave up

$$100 \times 9 = 900 \text{ calories.}$$

The melting of 10 gm. of ice produced 10 gm. of water at 0° C. and these were heated to 11° C. They therefore used up $11 \times 10 = 110$ calories during this final heating.

The remainder of the heat, $900 - 110 = 790$ calories, was used in melting 10 gm. of ice.

To melt 1 gm. of ice $\frac{790}{10} = 79$ calories were used, and this is the latent heat of fusion of ice.

The calculation may be tabulated as follows—

Heat lost by water = Heat gained by ice in melting and warming.

$$\begin{aligned} 100 \times 9 &= 10 \times X + 10 \times 11 \text{ calories.} \\ 900 &= 10X + 110 \text{ calories.} \\ 10X &= 790 \text{ calories.} \\ X &= 79 \quad \text{,,} \end{aligned}$$

Repeat this experiment and take the average of all the results obtained in the class. Note any sources of error that were apparent to you, remembering that in the calculation you have assumed that all the heat lost by the warm water was absorbed by the ice.

Just as there are two heats of vaporisation, there

are two heats of fusion, and for the same reason. What is this reason (see §§ 73, 75).

In the British system the heat of fusion is 147 B.T.U.
In the metric system the heat of fusion is 79 calories.

116. THE EXPANSION OF WATER ON FREEZING.—We have seen in §§ 47–49 that when water is cooled it attains its maximum density at 4° C. and that when further cooled it expands. Hence ice-cold water will be lighter than water at 4° C. and in a cold pond the water at 4° C. will be at the bottom and water colder than that will lie above it. Hence when freezing commences it is the surface that freezes first.

The ice does not go far below the surface, for ice is a bad conductor of heat, and the heat contained in the water at 4° C. at the bottom does not easily make its way through the ice. This provision of nature ensures the safety of fish in ponds and lakes.

When ice floats on water a good deal of it is above the surface. This shows that it is decidedly lighter than cold water. It could not have expanded very much in cooling from 4° C. to 0° C.; this would not account for the lightness of the ice. It seems to indicate that water expands on freezing, contracting again on melting. We will try some experiments to see whether this is so or not.

FIG. 75.

(*a*) Blow a bulb at the end of a piece of glass tubing. Draw out the tube just above the bulb and then fill it with water in the same way as a thermometer is filled. When cold again and quite full, break off the end and seal up in the blowpipe flame. Wrap the bulb in a piece of cloth and put it in a freezing mixture (§ 120)—that is, one whose temperature is below 0° C. State what happens to the bulb and explain it as far as you can.

(*b*) Obtain a flask fitted with a good cork and a long tube as in the sketch. See that the cork and tube are water-tight. How would you do this?

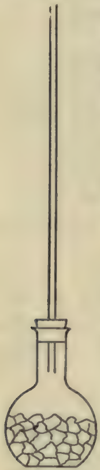


FIG. 76.

Into the flask place as much ice as possible. Fill it up with water and insert the cork and tube. Note the level of the water in the tube. Place the flask in a vessel of warm water and note what takes place. Explain your results as fully as you can.

As a result of these and other experiments we learn that **10 vols. of water in freezing become 10·9 vols. of ice.**

The behaviour of ice—water—steam—on being heated can be readily represented by a diagram, although, as you will easily understand, the distances cannot be drawn in exact proportion.

From the diagram below we see that 10 vols. of ice-cold water become 10·9 vols. of ice which on cooling contract again. The same 10 vols. of ice-cold water would have become 9·99 vols. of water at 4° C. and 10·43 vols. at 100° C. These on evaporating would become 17,126 vols. of steam, for, according to experiment, we find that 1 vol. of boiling water becomes 1642 vols. of steam at the same temperature. This steam on further heating continues to expand.

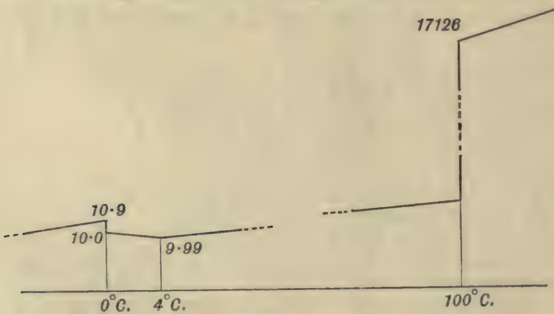


FIG. 77.

Mathematical Exercises—XXI.

1. What amount of heat is required to melt 30 gm. of ice?

2. How much heat is needed to melt 15 gm. of ice and to raise its temperature to 30° C.?

3. Calculate the heat required to convert 20 gm. of ice into steam at 100° C.

4. What will be the resulting temperature when 5 gm. of ice are melted in 35 gm. of water at 30° C.?

5. Calculate the (latent) heat of fusion of ice from the following experimental results—

   (*a*) 10 gm. of ice are added to 70 gm. of water at 20° C.; the final temperature being 7·5° C.
   (*b*) 12 gm. of ice when added to 60 gm. of water reduce the temperature from 22° C. to 5° C.
   (*c*) The temperature of 65 gm. of water at 18° C. is reduced to 8·5° C. by the addition of 8 gm. of ice.
   (*d*) 35 gm. of ice when added to 250 gm. of water reduce its temperature from 20° to 7·6° C.

6. What is the final temperature when 10 gm. of ice are added to 60 gm. of water at 30° C.?

7. How much steam must be blown through a mixture of 60 gm. of ice and 100 gm. of water in order that the whole of the ice may be melted without raising its temperature?

8. What temperature is attained when 12 gm. of steam are passed through a mixture of 20 gm. of ice and 100 gm. of water?

9. If the burning of a pound of coal produces sufficient heat to raise 7500 pounds of water 1° C., how many pounds of coal will be required to convert 150 lb. of ice into steam at 100° C.?

10. One hundred grams of ice are placed in a beaker containing 1000 gm. of water at 20° C. After all the ice has melted the temperature is 11° C. Calculate how much heat will be required to melt 1 gm. of ice and to raise its temperature to 11° C.

11. What is the fall in temperature produced by melting 53 gm. of ice in a vessel containing 220 gm. of water at 30° C.?

12. How much heat is lost by the ice when 45 gm. of water are frozen?

13. How much heat is lost when 30 gm. of steam at 100° C. are converted into ice at 0° C.?

14. How many grams of ice at 0° C. must be added to 90 gm. of water at 10° C. so that the vessel may contain equal masses of ice and water at 0° C.?

117. THE FORCE EXERTED BY WATER ON FREEZING. —Water on freezing expands, and in expanding exerts a great force. In the experiment described in a late paragraph we saw that a glass vessel containing water burst on freezing. If possible repeat the experiment using a metal vessel with a screw-on top. You will obtain a similar result. Even a vessel made of iron half an inch thick can be broken by the expansive force of freezing water.

We often hear the expression used that "the thaw has come and the pipes will burst." Some people say: "The thaw has come and we must look out for burst pipes." The former is distinctly wrong, for it is not on thawing that the water expands but on freezing. The pipes were broken when the hard frost came, but the ice closed up the breaks and it was not till the thaw came that the damage was apparent. Hence, though perhaps the intention of the second statement is wrong, its wording is correct.

To prevent breakages, pipes in exposed places are wrapped in felt or a small gas fire is kept burning while the frost lasts. A safety pipe has been suggested which is oval in section and not circular. The expansion will slowly convert the oval to a circle, for the area of an oval is less than that of a circle of the same circumference. In course of time, however, even with safety pipes breaks will come.

On many parts of the British coast the effect of the freezing of water is very disastrous. The summer heat cracks the rocks and the autumn rains fill the cracks. In winter, frosts widen them and with the thaws of spring there come extensive landslips. So extensive indeed are these landslips that in several parts

of the south of England, especially between Brighton and Dover, people are not allowed to walk along the unprotected cliffs in springtime.

118. HEAT OF SOLUTION.—We have seen that when ice is converted into water a certain amount of heat called the heat of fusion is absorbed. When water is converted into ice the heat will be given out again. Do other solids when converted into liquids act in the same way? Scientists have tried experiments on many other bodies and have found that all are alike in this respect.

Many common bodies will dissolve in other liquids but cannot be easily converted into liquids of the same substance. Ice and water are the same chemical substance. Salt and water are not the same substances. Still, in converting solid salt into a solution of salt heat is absorbed. This heat we call the heat of solution to distinguish it from heat of fusion, with which it is much akin.

119. *To show that bodies when going into solution absorb heat.*—Weigh out 100 gm. of water into a beaker and note the temperature. Add 5 gm. of solid "hypo" such as photographers use and note the temperature after the hypo has dissolved. Add another 5 gm. and note the temperature again. Repeat this time after time and draw a graph from the results. Let the vertical line of the graph represent temperature and the horizontal line hypo.

What deductions do you draw?

Is the graph a straight line—that is, is the change in temperature the same for each successive addition of hypo? If not, suggest any reasons you can think of for it being as it is.

What has become of the heat which seems to be lost?

Other substances, such as salt and washing soda, will be found to give similar results. Try some of these.

120. Freezing Mixtures. — Suppose now we put both ice and salt into water, the ice in melting would require heat — heat of fusion; the salt in dissolving would require heat—heat of solution. The two together would require more heat than either alone and would reduce the temperature of the mixture more. Try this for yourself and determine what proportion of ice and salt will produce the lowest temperature. Try first equal quantities of each, then twice as much of one as of the other.

Such a mixture as this is known as a freezing mixture, as it is much used for freezing purposes. It is frequently used in making ice cream. Other freezing mixtures can be made of—

(*a*) Sodium sulphate and ice or snow.
(*b*) Calcium chloride and ice or snow in the proportion of 4 of the former to 3 of the latter. This sometimes produces a temperature as low as $-51°$ C.

Try these and note the lowest temperature that each mixture produces.

121. Melting Point. — Most of the experiments recently suggested and discussed have dealt with the freezing of water or the melting of ice. It would be well to inquire whether other substances behave in the same way. For instance, let us inquire first of all whether all substances melt at the same temperature. A little thought will show at once that they do not do so. Give one or more reasons for coming to this decision. At what temperatures, then, do other substances melt? To find this out we must resort to an experiment.

122. *To find the melting point of wax.* — Water and ice are quite common articles and in using them we need not restrict ourselves much in the quantities employed. It is not so, however, with most substances. Suppose that only a small quantity of wax is provided.

Draw out a capillary tube from a piece of glass tubing by holding it in the flame and revolving it till it is soft. Then taking it out of the flame draw your hands steadily and quickly apart. Break off a piece of this tubing and draw up into it some of the melted wax. Seal up the lower end of the tube in the flame and, breaking off a suitable length, attach it by wire to the bulb of the thermometer.

Place the latter in a wide test tube and gently warm it. The solid wax is opaque, the melted wax is more transparent. Note the temperature at which this transparency is first noticed. Now gently cool the test tube and note the temperature at which the transparency disappears. The mean between the two readings will give the true melting point.

Why is it necessary to take these two readings?

Repeat the experiment with other substances.

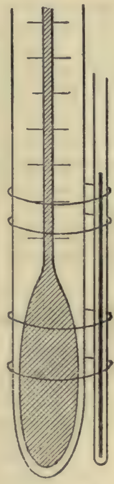


FIG. 78.

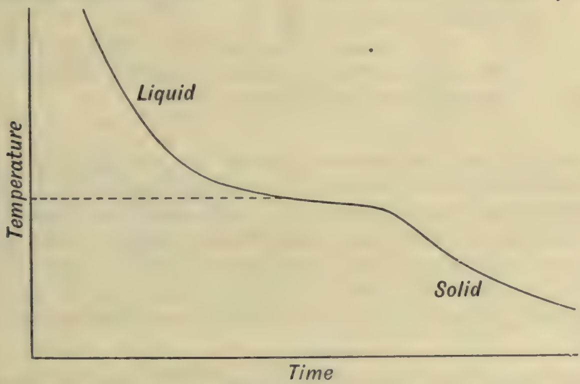


FIG. 79.

123. *The cooling curve method.*—

Obtain a large test tube (6 in. by 1 in.) and half fill it with melted wax. Put a thermometer into the wax and

place the tube where it is out of draughts. Note the temperature each minute (or half minute). From the results construct a graph, giving the connection between time and temperature. Let the vertical line represent temperature and the horizontal one time. The result will be somewhat as follows—

The first, or upper, portion of the curve represents the cooling while in the liquid condition. The lower portion represents the cooling while in the solid condition.

The practically horizontal portion between the two represents the change from the liquid to the solid condition and the temperature corresponding to it will give the melting point.

124. LAWS OF FUSION.—We are now in a position to state some of the laws of fusion.

(1) Each substance begins to fuse (melt) at a definite temperature which is always the same for the same substance.
(2) The temperature of fusion remains the same during the whole of the change—that is, until fusion is completed.
(3) Each unit mass of substance absorbs during fusion a certain quantity of heat termed the (latent) heat of fusion.

125. *Do all substances expand on solidifying?*—We have already seen that water expands on freezing. Try whether the same thing occurs with other substances.

Take some other substance which readily melts and, placing it in a wide test tube, melt it and note the level of the liquid. Cool the substance till solid. Does the substance show any signs of contraction or expansion?

126. GLACIERS.—In every country there is a certain altitude above which snow never melts. This altitude is called the snow line. At the equator, near Quito, it is 16,700 ft. up, while it reaches sea-level near the poles. The continued accumulation of snow above

the snow line gives rise to glaciers. Partly by the pressure of the overlying snow and partly by freezing, the bottom of the snow fields become converted into ice. This ice escapes in the solid form as glaciers or rivers of ice flowing down valleys towards the sea. A line of stakes driven into the ice across a glacier shows that the ice moves like a river—faster in the middle than at the sides. The motion is, of course, much slower than a river, being sometimes only an inch or two a day and in other cases a few feet.

127. REGELATION. — When a glacier encounters a projecting immovable rock in its path the ice does not break but flows round the rock just as a river would do. Let us examine this more closely. Obtain a block of ice and support it as indicated in the diagram. Pass a loop of thin copper wire over the ice and hang on it a weight of 30 lb. or more. Have patience and observe what happens. The wire will eventually cut through the ice without dividing the block into two parts.

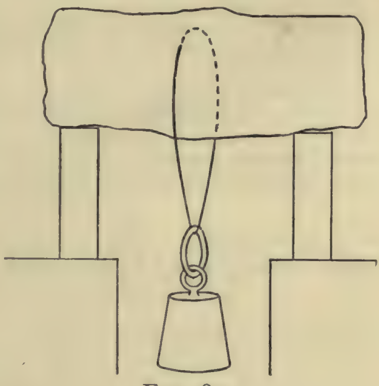


FIG. 80.

Before trying to explain this, do the following experiment: Press together with a good deal of force two pieces of ice. What happens? While you are pressing notice that the surfaces easily slide over each other. When you release the pressure the two pieces stick together.

The above experiments are examples of what is known as "regelation."

Now we have seen in a previous part of this section that water at 0° C. occupies a smaller volume than the ice it forms at 0° C. Hence anything that tends to diminish the volume of ice helps it to liquefy. If, then, we compress ice at 0° C. it changes to water. On the other hand, releasing the pressure allows the water to freeze again. In other words, **pressure lowers the freezing point of water.**

You should now be able to explain the above two experiments, and also the motion of a glacier past projecting rocks in its bed.

Questions and Problems—XVI.

1. Why is it more difficult to make snowballs on a very cold day than on a day when the temperature is near 0° C.?

2. In the experiment with the block of ice and the loop of copper wire why is it better to have a thin wire?

3. It is found to be difficult to skate when the temperature is many degrees below zero. Can you give a reason?

4. Why are the best skates hollow ground?

128. Icebergs. — In warm countries glaciers melt before reaching the valleys, giving rise to rivers, but in

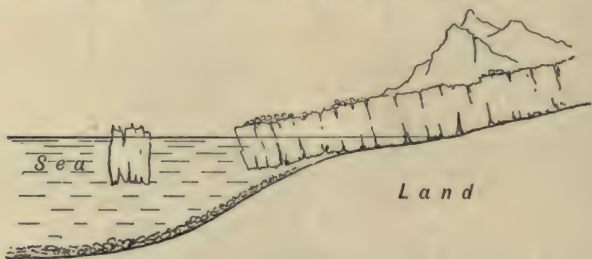


Fig. 81.

far northern countries where the snow line is at or near the sea-level, glaciers flow from the mountains through

the valleys right down to the sea, where they break up into icebergs. The central plateau of Greenland is one vast snow field from which glaciers are always flowing to the sea.

Numerous icebergs are formed and carried southward by the Labrador current. The heat of fusion of ice (*i. e.* the heat required to change 1 gm. at 0° C. into water at 0° C.) is rather big, and therefore these icebergs travel long distances before they disappear. One will recall in this connection the disaster to the biggest vessel afloat—the *Titanic*—in 1912.

Now do this experiment. Put fairly large blocks of ice into a trough of water and take rough measurements of the submerged portions and of the parts above the surface. When ice floats in water what fraction of the whole is submerged?

Does a knowledge of this fraction give you the specific gravity of ice?

Why are icebergs so dangerous to ships?

The volume of an iceberg showing above the water is 5686 cubic metres. Taking the specific gravity of ice as 0·917, find the mass of the iceberg.

Questions and Problems—XVII.

1. The water cistern and distribution pipes of a certain house are under the roof. What would you do in cold winters to prevent the pipes from bursting?

2. How is ice cream made?

3. Discuss the advantages and disadvantages of putting salt on the doorstep during frosty weather.

4. How is it that the fish are not destroyed when a lake is frozen over?

5. Large lakes, such as Lake Superior, when frozen over during the winter are said to retard the coming of the spring. Explain this.

6. Why does ice float on water?

7. During a winter frost, if snow begins to fall, the temperature of the air will rise to 32° F. Explain why this is so.

8. Discuss the common saying "the pipes have burst for the thaw has come."

9. Farmers say that a hard frost is good for the soil. What good can the frost do?

10. How is it that icebergs are often seen in the temperate zone?

11. Can you give any reasons for the fact that sleet falls chiefly in spring and winter and very rarely accompanies a storm?

12. Table Mountain in Cape Colony is generally covered by a cloud, making it look like a table covered by a tablecloth. What is the cause of the cloud?

13. A bottle is filled with melted tallow, well stoppered and quickly cooled. What happens? What would have happened if water had been used instead of tallow?

14. Explain the action of making a snowball.

15. In winter why is salt thrown upon "slides"?

SECTION VII

SPECIFIC HEAT

129. TEMPERATURE. — When reviewing back work there are one or two facts which have to be firmly fixed in our minds. **In the first place, we have noticed that when hot and cold bodies are in contact, heat passes from the hot to the cold one until both are alike in temperature.** The hot body is said to have a higher temperature than the cold one. When, however, they are in contact they acquire the same temperature. Heat is not the same as temperature, for heat is that something which passes from the hot body to the cold one, while temperature is the name given to the condition in which the hot body exists.

The difference between heat and temperature may be better understood by a simple analogy. Suppose there are two cisterns, in one of which the water level is high, while in the other it is much lower. Imagine them connected by a pipe. Then, because of the difference between the water levels, water will flow from the higher level to the lower till both levels are alike. In a similar way if two bodies are of different temperatures and are brought into contact (*i. e.* they are connected), heat will flow from the one of higher temperature to that of the lower till the temperatures of both are alike.

Try the following experiment: Bend a glass tube as in the diagram. Place one end in a jar (A) of water

and suck the other end till the water flows. Collect the water in a second jar B. The water is now flowing from A to B because A has a higher water level than B. When A is nearly emptied raise B and lower A so as to reverse the levels. Describe exactly what happens, and as far as you can, give the reasons for the flow of liquid. A bent tube used in this way is called a siphon.

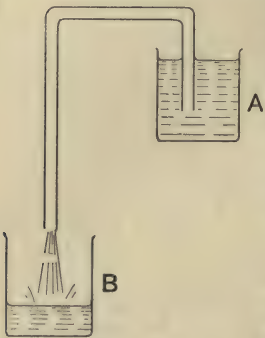


FIG. 82.

130. THE MIXING OF HOT AND COLD BODIES.—The second point that requires attention is the work we have already done on the mixing of hot and cold bodies and the amount of heat that passes from one to the other. We have seen how to measure this heat in several cases, but these have all dealt with water and its forms of ice and steam. We will repeat some of the experiments with water and then extend them to other substances.

Mix equal quantities of hot and cold water and note the temperature of the mixture. Calculate what the temperature of the mixture should be and see whether the answer agrees with the experimental result. If it does not, try to find the reason. Note the working of the following problem—

Problem.—Fifty grams of water at 60° C. are mixed with 50 gm. of water at 10° C. What is the temperature of the mixture?

Let the temperature of the mixture $= x°$ C., then—

$$\text{Heat gained by cold water} = \text{Heat lost by hot water.}$$
$$50 \times (x - 10) = 50 \times (60 - x) \text{ cals.}$$
$$x - 10 = 60 - x$$
$$2x = 70$$
$$x = 35° \text{ C.}$$

Repeat the experiment and calculation using unequal quantities of water at different temperatures.

Mix 50 gm. of hot copper with 50 gm. of cold water. Note the temperature of the mixture. The copper may be heated in a test tube held in the neck of a flask in which water is being boiled.

Suppose the temperature of the copper was 100° C., that of the water 10° C., and that of the mixture 18° C.

Then heat gained by water $50 \times 8 = 400$ cal.; = heat lost by copper.

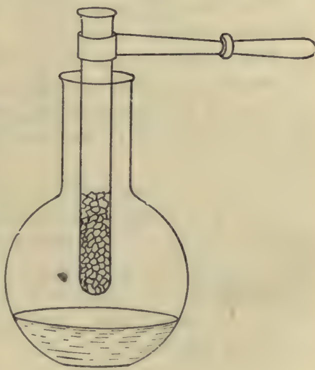


FIG. 83.

50 gm. of copper cooled 72° C. lost 400 cal.

1 ,, ,, ,, 72° C. ,, $\frac{400}{50} = 8$ cal.

1 ,, ,, ,, 1° C. ,, $\frac{8}{72} = \frac{1}{9}$ cal.

That is to say, 1 gm. of copper cooled 1° C. loses $\frac{1}{9}$ cal. and vice versa; 1 gm. of copper heated 1° C. requires $\frac{1}{9}$ cal. instead of 1 cal. as water would do.

This seems to indicate that copper does not require as much heat as water does to raise its temperature.

Try the same experiment with other substances, such as lead shot, iron nails, etc., and see whether the same result holds good, that many substances require less than 1 cal. of heat to raise 1 gm. through 1° C. We have assumed that water requires 1 cal. per gm. to raise its temperature 1° C.

131. Specific Heat.—**The amount of heat required by 1 gm. of a substance to raise its temperature 1° C. is called the specific heat of the substance.**

How would you define specific heat when using the British system of units?

The specific heat of water is 1. This means that 1 gm. of water requires 1 unit of heat to raise it 1° C. This is almost the same definition as we have already adopted for unit of heat or calorie (see § 73).

132. Determination of Specific Heat.—There are several ways of determining the specific heat of a body. Each has its advantages and disadvantages. In all cases, however, there is a mixing of a hot and a cold body together and an equating of the gains in heat against the losses.

The chief methods are—

(1) The method of mixtures.
(2) The ice calorimeter method, depending upon the amount of ice melted by the addition of the hot body whose specific heat has to be detemined.

133. *The method of mixtures* (1).—The substance whose specific heat has to be determined (copper turnings are suitable) is heated to 100° C. by placing it in a test tube in the neck of a flask (see Fig. 83) in which water is boiling. After five or six minutes the temperature of the substance can be taken as 100° C., or a thermometer may be placed in the middle of it and the heating continued till the thermometer registers nearly 100° C.

The hot copper is then quickly tipped into some water, the weight and temperature of which are already known. After quickly stirring, the temperature of the mixture is taken. The results are tabulated as follows—

Results—

Mass of copper	= C gm.
,, water	= W gm.
Temperature of copper . . .	= T° C.
,, water . . .	= t° C.
,, mixture . .	= τ° C.

When calculating the quantity of heat given out or taken in one must now be careful to allow for the quantity called specific heat. This has not yet come into our calculations.

Suppose m gm. of a substance of specific heat S lost θ° C. in temperature. Then, commencing with our definition of specific heat, we have—

1 gm. of the substance heated 1° C. requires S units of heat
or

1	,,	,,	cooled	1° C. loses	S	,,

and

m	,,	,,	,,	,,	,,	mS	,,
m	,,	,,	,,	θ° C.	,,	$mS\theta$	,,

The quantity of heat lost or gained during a change in temperature is equal to the product of the weight of the body, its specific heat and its change in temperature.

The formula $m \,.\, \text{S} \,.\, \theta$ is used to represent the quantity of heat lost or gained during a temperature change.

Going back now to our experiment—

$$\text{Heat lost by copper} = \text{Heat gained by water}$$
$$m \,.\, \text{S} \,.\, \theta = m \,.\, \text{S} \,.\, \theta$$

Using symbols $\text{C} \,.\, \text{S} \,.\, (\text{T} - \tau) = \omega \,.\, 1 \,.\, (\tau - t)$

and as all terms are known (see results) except S, then S can be calculated.

Perform this experiment and, if working in class, obtain the average class result.

Mathematical Exercises—XXII.

1. If 235 units of heat are required to raise the temperature of 200 gm. of a substance through 11° C., what is the specific heat of the substance?

2. The specific heat of lead is ·031. How many units of heat will be required to raise the temperature of 15 gm. of lead through 60° C.?

3. Twenty grams of water at 30° C. are mixed with 30 gm. at 100° C. What is the temperature of the mixture?

4. What quantity of heat is required to raise the temperature of 80 gm. of alcohol (specific heat ·62) from 15° C. to 48° C.?

5. What quantity of heat is required to raise 250 gm. of mercury from 10° C. to 60° C., the specific heat of mercury being ·033?

6. A piece of lead (specific heat ·031) weighing 120 gm. is heated to 100° C. It is then dropped into water at 15° C. which it heated to 17° C. What is the weight of the water?

7. Three hundred grams of lead at 100° C. are placed in 250 gm. of water, the temperature of which is thereby raised from 15° to 18° C. What value does this give for the specific heat of lead?

8. A mass of copper (specific heat ·095) weighing 200 gm. is heated to 100° C. and is placed in 110 gm. of alcohol at 10° C. The temperature rises to 30° C. Find the specific heat of alcohol.

9. Twenty grams of common salt at 96° C. are put into 200 gm. of turpentine at 15° C. The temperature rises to 19° C. If the specific heat of turpentine is ·43, what is that of common salt?

10. A ball of platinum weighs 200 gm.; it is placed in a furnace and then quickly transferred to a vessel containing 350 gm. of water at 0° C. The temperature rises to 30° C. What was the temperature of the furnace? [Specific heat of platinum = ·032.]

[*In the following problems it must be remembered that the density of a body is the mass of* 1 *c.c. of it, and that therefore mass = density × volume.*]

11. Calculate the amount of heat required to raise 35 c.c. of lead from 0° C. to 100° C., the specific heat of lead being ·031 and its density 11·4 gm. per c.c.

12. Taking the specific heats of iron and alcohol as ·112 and ·64 respectively, compare the amounts of heat required to raise equal volumes of iron and alcohol through equal differences of temperature. The density of iron is 7·7, that of alcohol ·8 gm. per c.c.

13. Two hundred grams of iron at 100° C. are placed in 50 c.c. of turpentine at 15° C. The temperature rises

to 61° C. Taking the specific heat of iron as ·112 and the density of turpentine as ·87 find the specific heat of turpentine.

14. A piece of aluminium weighing 160 gm. and of specific heat ·214, is raised to 90° C. and is then dropped into 50 c.c. of glycerine at 10° C. The temperature rises to 49° C. Find the specific heat of glycerine, taking its density as 1·26 gm. per c.c.

134. A Criticism.—In the experiment last described we assumed that when the hot copper was placed in the cold water, all the heat given out by the hot body is taken in by the cold body, which therefore rises in temperature. We must see how far this assumption is justified.

The copper was heated in a test tube — was this a good substance for carrying the heat? Can you suggest a better material for the tube?

Would it have been better merely to hang a solid piece of copper by a thread in the steam or boiling water so as to make it hot? If this had been done would it have introduced any error in the calculation? Was the copper the only hot substance in the mixture?

It was assumed that the copper was at 100° C. when placed in the cold water. Was it so? Did it, or did it not, lose heat in being transferred from the heater to the water? Could this loss of heat be allowed for? If not, it should be prevented. Can you suggest any method for doing it?

After the hot body was placed in the cold water the heat is supposed to have gone only into the latter. Did any of the heat pass into any other body?

135. *The determination of the specific heat of a solid.*—The last criticism has shown that to get a good result—

(*a*) The hot body must be dry.
(*b*) Its temperature must be accurately known.
(*c*) No heat must be lost in the transfer.
(*d*) Loss of heat to the air must be prevented.
(*e*) The heat taken up by the vessel holding the water must be allowed for.

Try the experiment again, using an improved heater. It consists of an inner copper tube surrounded by a steam jacket. Through the cork passes a thermometer and a thread holding the solid (zinc) whose specific heat has to be determined, close to the bulb of the thermometer. When the temperature nearly reaches 100° C. it is observed accurately and the thread burnt. The solid drops into a copper vessel momentarily placed beneath.

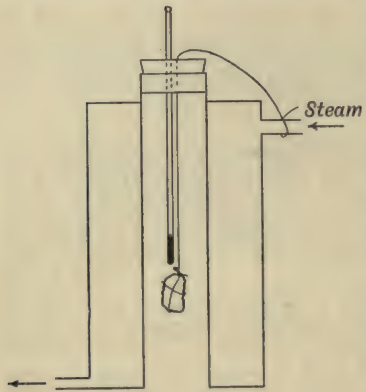


FIG. 84.

Note results as usual—

Weight of zinc	=
,, vessel	=
,, water	=
Temperature of zinc	=
,, water . . .	=
,, mixture . . .	=

The calculation is performed as usual—

Heat gained by water and vessel = Heat lost by zinc

$$m \,.\, \mathrm{S} \,.\, \theta + m \,.\, \mathrm{S} \,.\, \theta = m \,.\, \mathrm{S} \,.\, \theta$$

(Each $m\mathrm{S}\theta$ refers only to the substance named above it.)

The vessel holding the water is generally made of copper and from its use is known as a calorimeter. The specific heat of copper is ·095.

Criticise this method, noting down its advantages and disadvantages. Take note especially of any ways in which heat is lost and unaccounted for. Does the calorimeter with its contents gain any heat except from the hot zinc?

136. Heat Capacity and Water Equivalent.—The term heat capacity is frequently used with regard to the quantity of heat that a body has to take in when its temperature is raised 1° C. Heat capacity (or capacity for heat) refers to the whole body, while specific heat only refers to unit mass of it.

The heat capacity of a body is the quantity of heat required to raise the whole body 1° C.

It is manifestly equal to the product of the mass of the body and the specific heat of the material it is made of.

$$\begin{aligned}\text{Heat capacity} &= \text{mass} \times \text{specific heat}\\ &= \text{M}\,.\,\text{S}.\end{aligned}$$

When the object under consideration is a calorimeter then the heat capacity is known as the water equivalent of the calorimeter.

$$\begin{aligned}\text{Water equivalent} &= \text{mass} \times \text{specific heat}\\ &= \text{M}\,.\,\text{S}.\end{aligned}$$

The water equivalent of a calorimeter is that amount of water which requires as much heat as the calorimeter does to raise it through the same range of temperature. Hence, if the water equivalent of the calorimeter be added to the mass of water contained in it, no further notice need be taken of the vessel.

As an example, suppose that the calorimeter weighed 34 gm., that it was made of copper, of specific heat ·095, and that it contained 150 gm. of water.

Now the water equivalent of the calorimeter would be $\text{M}\,.\,\text{S} = 34 \times {\cdot}095 = 3{\cdot}23$.

If now we consider the mass of water to be 153·23 gm. instead of 150 gm., then no further notice need be taken of the calorimeter, for the 3·23 gm. of water will absorb as much heat (or lose as much) as the calorimeter does in rising or falling 1° C. The heat capacities are the same.

137.—

TABLE OF SPECIFIC HEATS.

Lead	·0305 cal.
Mercury . . .	·033 cal.
Tin	·0552 cal.
Zinc	·093 cal.
Brass	·090 cal.
Copper . . .	·0936 cal.
Iron	·119 cal.
Sulphur . . .	·163 cal.
Glass	·16 cal.
Aluminium . .	·219 cal.
Air	·237 cal. at constant pressure
Turpentine . . .	·420 cal.
Ice	·502 cal.
Steam	·465 cal. at constant pressure
Glycerine . . .	·58 cal.
Alcohol . . .	·62 cal.
Hydrogen . . .	3·402 cal. at constant pressure

MATHEMATICAL EXERCISES—XXIII.

(*Refer to table of specific heats when necessary.*)

1. Calculate the heat capacity of (*a*) 300 gm. of lead, (*b*) 250 gm. of zinc, (*c*) 25 gm. of glycerine, (*d*) 150 gm. of iron, (*e*) 5 gm. of hydrogen.

2. What mass of aluminium has the same heat capacity as 200 gm. of tin?

3. What mass of water has the same capacity for heat as 25 gm. of copper?

4. What is the water equivalent of—

(*a*) A copper calorimeter weighing 28 gm.
(*b*) An aluminium calorimeter weighing 15 gm.
(*c*) A tin calorimeter weighing 20 gm.
(*d*) A glass vessel weighing 6·6 gm.

138. *To find the water equivalent of a calorimeter.*—We already know one method, which is to weigh the vessel and then find the product of mass and specific heat.

The water equivalent may be found directly as follows—

Into the vessel place a known weight of cold water. Take its temperature and add a known weight of hot

water, the temperature of which is known. Find the weight and resulting temperature of the mixture after stirring it.

Then, equating gains and losses of heat, we have—

$$\text{Heat gained by calorimeter and cold water} = \text{Heat lost by hot water}$$

$$\omega\theta + m\,.\,\mathrm{S}\,.\,\theta = m\,.\,\mathrm{S}\,.\,\theta$$

where ω = water equivalent.

When doing the experiment try and arrange so that but little heat is lost to the air around.

How would you prevent heat passing through the base of the calorimeter into the table below?

139. *To find the specific heat of a liquid.*—Arrange an experiment for finding the specific heat of a liquid by the method of mixtures; that is, by mixing a hot body with a cold one.

When arranging the experiment remember that—

(*a*) Mercury must not be used with copper, etc. Mercury combines with some metals and there is a rise in temperature due merely to this combination. Use iron.

(*b*) Certain liquids must not be mixed as there is frequently a change in temperature owing to the mixture. Thus water and alcohol when mixed rise in temperature.

Mathematical Exercises—XXIV.

1. The specific heat of alcohol being ·62, its boiling point 78° C., and its heat of vaporisation 207, what amount of heat is required to raise 25 gm. of alcohol from 15° C. to its boiling point and to boil it all away?

2. Lead melts at 327° C.; it has a specific heat of ·031 and its heat of fusion is 5. How much heat is required to melt 150 gm. of lead initially at 15° C.?

3. One hundred and fifty grams of a substance at 10° C. are placed in a calorimeter (water equivalent = 10 gm.) containing 130 gm. of water at 20° C. The final temperature is 18° C. Find the specific heat of the substance.

4. A piece of metal of specific heat ·114 is raised to 100° C. and then dropped into 100 gm. of water contained in a calorimeter whose water equivalent is 20 gm. The temperature of the water is raised from 10° C. to 20° C. What was the mass of the metal?

5. If 203 units of heat are required to raise the temperature of 170 gm. of a substance through 8° C., what is the specific heat of the substance?

6. A copper calorimeter weighing 53 gm. contains 110 gm. of water. A piece of copper weighing 90 gm. is raised to 100° C. and placed in the water, the temperature of which is thereby raised from 10° C. to 16·5° C. Calculate the specific heat of copper.

7. A piece of metal at 10° C. and weighing 250 gm. is placed in a calorimeter which, with its contents, has a water equivalent of 150 gm. The water is cooled from 42° C. to 37° C. Calculate the specific heat of the metal.

8. Forty grams of water at 60° C. are added to a copper calorimeter containing 10 gm. of water at 13° C. The temperature rises to 48° C.; calculate the water equivalent of the calorimeter. Taking the specific heat of copper as ·095, what was the weight of the calorimeter?

9. What is the resulting temperature when 20 gm. of water at 10° C. and 100 gm. of mercury at 150° C. are mixed?

140. THE ICE CALORIMETER.—In the previous work we have found the specific heat of solids by mixing a hot body with a cold one and noting the changes in temperature. The specific heat can also be found by placing the hot body on ice and noting the amount of ice melted. For every gram of ice melted 80 units of heat were given out by the hot body when its temperature fell to 0° C. Instruments which can be used in this connection are called "ice calorimeters."

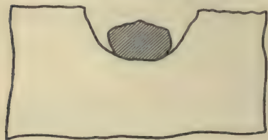


FIG. 85.

The first of any note was Black's. He obtained a block of ice in the centre of which a hole was scooped. This hole was dried, the hot body placed in it, and the water produced was turned out and weighed.

Results—

Mass of metal	= 240 gm.
Temperature of metal . . .	= 100° C.
Mass of water produced . .	= 31 gm.

From these results calculate the specific heat of the metal. What metal do you think it was?

Black recommended that the piece of ice should be covered by another slab; what advantages would this possess? Criticise this experiment. What are the chief disadvantages of the method? Suggest methods for collecting all the water produced in the hollow. How would you prevent water formed at A from running back into the hollow when the cover is removed?

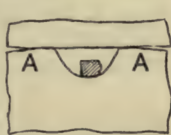


FIG. 86.

Adam Black, who first suggested this process, was born at Bordeaux in 1728. He became professor of chemistry at Glasgow in 1756 and at Edinburgh ten years later. He was the first to write much about specific heat and was the discoverer in 1761 of the heats of fusion and vaporisation which he called "latent heat," a name which is not a good one, but which has remained in use ever since.

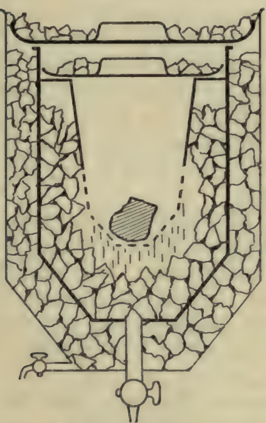


FIG. 87.

141. LAVOISIER'S ICE CALORIMETER.—This instrument was invented by the French chemist as an improvement on Black's. It consists of a copper vessel A, surrounded on all sides by an ice jacket which in its turn is again surrounded by another ice jacket as in the diagram. In this way the inner ice jacket is kept at 0° C. and unaffected by the outside air.

The water produced by the introduction of the hot solid into the inner vessel is run off by a tapped tube.

In what ways is this an improvement on Black's apparatus? Consider each of the disadvantages of the latter and note down whether it is avoided in this calorimeter.

It is to be noted that the amount of the water produced has to be multiplied by 79 when determining the heat set free by the body experimented with. Any error in the measurement of the water will also be multiplied by 79. In this way a considerable final error may be introduced.

*142. BUNSEN'S ICE CALORIMETER.—This is a considerable improvement on the other two, but it is an instrument that requires a great deal of practice before satisfactory results can be obtained.

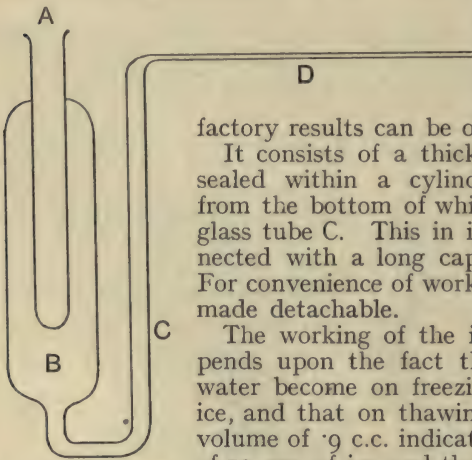


FIG. 88.

It consists of a thick glass tube A sealed within a cylindrical bulb B, from the bottom of which runs a wide glass tube C. This in its turn is connected with a long capillary tube D. For convenience of working D is often made detachable.

The working of the instrument depends upon the fact that 10 c.c. of water become on freezing 10·9 c.c. of ice, and that on thawing a change of volume of ·9 c.c. indicates the melting of 10 gm. of ice and the absorption of $10 \times 79 = 790$ calories of heat.

The preparation of the instrument requires that the whole of the tube C, a small portion of D and the lower part of B should be filled with mercury, while the rest of B is entirely filled with air-free water.

Suppose now that the instrument is filled ready for

use. The next step is to obtain a layer of ice in B surrounding the lower part of A. The formation of this presents a difficulty inasmuch as the freezing of the water in A may occur throughout and the expansion produced be sufficient to break the vessel.

The water is frozen by placing a little ether in A and blowing through it to produce rapid evaporation. Explain the action of this in producing the ice. Another method is to place some solid carbon dioxide in A and allow it to evaporate. The latter method is the better, but requires careful manipulation.

The position of the mercury thread in D is now noted. The hot body is placed in A and some of the ice is melted. Consequently the volume of the ice and water contracts and the mercury in D recedes. The distance through which the mercury thread has moved is noted and, as the tube is accurately graduated, this length can be converted to a corresponding volume.

We now know the mass of ice melted and hence the amount of heat given out by the cooling of the body (of mass m and temperature $t°$ C.) to 0° C.

This instrument is particularly useful in measuring the specific heat of small bodies. For instance, it was used by Weber for finding the specific heat of diamonds.

*143. PROBLEM.—In a given experiment the introduction of a piece of metal weighing 2·5 gm. and at 100° C. caused the mercury column to recede 1·8 cm., the bore of the tube being such that 64 cm. in length had a volume of 1 c.c. Find the specific heat of the metal.

A length of 64 cm. $= 1$ c.c.

,, 1·8 cm. $= \frac{1{\cdot}8}{64}$ c.c. $= {\cdot}028125$ c.c.

·9 c.c. contraction is equivalent to the melting of 10 gm. ice, *i. e.* to 790 cal.

1 c.c. contraction is equivalent to $\frac{790}{{\cdot}9}$ cal.

$\therefore$ ·028125 c.c. contraction is equivalent to

$$\frac{790}{\cdot 9} \times \frac{1 \cdot 8}{64} \text{ cal.}$$

$$= 24 \cdot 7 \text{ cal.}$$

Heat lost by metal $= m \,.\, S \,.\, \theta.$

$$= 2 \cdot 5 \times x \times 100 = 24 \cdot 7$$

$$\therefore x = \frac{247}{2500} = \cdot 099 \text{ cal.}$$

*144. Problem 2.—Twenty-five grams of water at 20° C. are placed in the tube of the bunsen ice calorimeter; the mercury moves through 36 cm. Twenty grams of metal at 100° C. are placed in the tube and the mercury moves through 20 cm. Find the specific heat of the metal.

25 gm. water cooling 20° give out 500 cal.

A mercury movement of 36 cm. = 500 cal.

,, ,, 1 cm. $= \frac{500}{36}$

,, ,, 20 cm. $= \frac{500 \times 20}{36} = \frac{2500}{9}$

Heat given out by metal $= m \,.\, S \,.\, \theta$

$$= 20 \times x \times 100$$

which is equal to $\frac{2500}{9}$ cal.

$$\therefore 2000\, x = \frac{2500}{9} \text{ cals.}$$

$$x = \frac{25}{20} \times \frac{1}{9} = \frac{5}{36}$$

$$= \cdot 0139$$

$$\therefore x = \cdot 014 \text{ nearly.}$$

Mathematical Exercises—XXV.

(Take the heat of fusion of ice as 79·5.)

1. Equal masses of iron and copper are heated to 100° C. and placed on a piece of ice. The former melts 24 gm. of ice, the latter 20 gm. Compare their specific heats.

2. Two hundred and seventy-two grams of mercury at 60° C. are placed in the hollow of a Black's ice calorimeter, causing 6·8 gm. of ice to melt. What is the specific heat of mercury?

3. A piece of iron weighing 500 gm. is heated in a bunsen flame to 300° C. It is then dropped into a mixture of ice and water. What weight of ice is melted?

4. It is found that 32 gm. of metal at 100° C. will just melt 4 gm. of ice. What is the specific heat of the metal?

*5. The cross section of the capillary tube of a bunsen ice calorimeter is 1·8 sq. mm. Ten grams of a substance at 60° C. are introduced into the inner tube, causing the end of the mercury to move through 3·5 cm. Find the specific heat of the metal.

*6. Twenty-two grams of a certain substance at 100° C. are placed in a bunsen ice calorimeter. It caused the end of the mercury column to move through 8 cm., the section of the tube being 1 sq. mm. Calculate the specific heat of the substance.

*7. A piece of copper weighing 15 gm. and of specific heat ·095 is heated to 100° C. and then placed in the bunsen calorimeter. Through what distance did it make the mercury level move? The cross section of the capillary tube is 1 sq. mm.

*8. The cross section of the capillary tube of a bunsen ice calorimeter is 1 sq. mm., and the movement of the mercury is through 10 cm. when 4·2 gm. of a substance at 95° C. are introduced. Calculate the specific heat of the substance.

145. Specific Heat.—Refer back to the table of specific heat in § 137. You will there see that the specific heats of different substances vary very considerably.

Which substance has the lowest specific heat?
Which substance has the highest?

Do the specific heats of solids differ materially from those of liquids? If so, which are the higher?

Are the specific heats of gases greater or lower than those of liquids?

Has water got a comparatively high or low specific heat? Is the specific heat of ice higher or lower than that of water? Is that of steam higher or lower than that of water?

146. SPECIFIC HEAT IN NATURE.—These questions arise: Does the specific heat of a body effect its uses in nature? Do these quantities, which are all somewhat small, have any effect on natural occurrences around us?

We sit in the sun on the dry sandy shore of a popular watering-place; the sand is almost too hot for the hand to be placed upon it. Its specific heat is low. Only a little heat is required to raise its temperature, and the noonday heat of the sun is enough to make it almost unbearable. But move into a shaded spot; how cold the sand feels. Why is this, when the sun is making places around so hot? Move on further to the wet sand. It never seems to get hot. The specific heat of the water is high, and it takes a great deal of heat to raise its temperature even a few degrees.

Examples such as these may be multiplied almost indefinitely. They all show that specific heat plays an important part in nature, more especially in the case of water, whose specific heat is almost the highest of all. Only one liquid has a higher specific heat; add alcohol to water and the specific heat rises. It attains its maximum when we have a 20 per cent. solution of alcohol. As the strength then increases the specific heat decreases until with pure alcohol it is no more than ·62.

147. THE HIGH SPECIFIC HEAT OF WATER.—The fact that water has a very high specific heat has far-reaching effects on the climate of the world.

1. The sea acts as a vast storehouse of heat, absorbing it readily during the hot seasons, distributing it again during the colder seasons. In this way districts near the sea have a far more equable climate than those further inland. The temperature range of Greenwich—that is, the difference between the average July temperature and average January temperature, is 24° F., while those of Berlin, Warsaw and Saratof, in the same latitude, are 35° F., 41° F. and 57° F. respectively. Seaside places, such as Brighton, Scarborough and

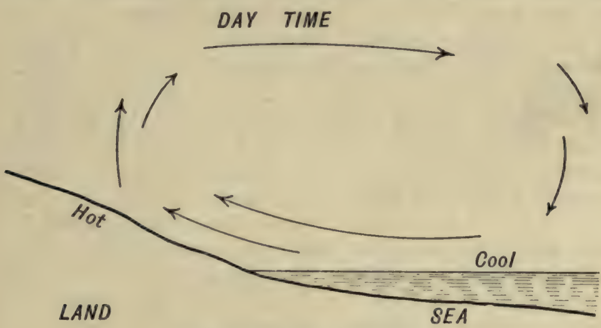


FIG. 89.—SEA BREEZE.

(Draw the corresponding diagram for the **evening breeze.**)

Bournemouth, are warmer during the winter and cooler during the summer than places further inland.

2. The land with its lower specific heat gets much hotter than the sea on summer days, and this difference in temperature affects the air above. Hence, convection currents start and we have sea breezes blowing during the day. Conditions, however, are changed as soon as the sun is going down, for the land, of low specific heat, is falling in temperature more rapidly than the sea, and the evening **land breeze** is the result of the consequent convection currents.

3. In tropical countries the rise in the temperature of the land is very great and the resulting upward

convection current is supplied with the moist air from the neighbouring seas and lakes. The air is thus moisture laden, and as it rises it expands and cools and the torrential **rainstorms of equatorial regions** are the result.

4. The convectional currents of tropical regions are accompanied by winds blown inwards from north and south towards the equator. These are constant in their direction, but owing to the inclination of the earth on its axis the sun appears to be vertically over the equator only in March and September. At the end of June the sun appears to be vertically over places $23\frac{1}{2}°$ north of the equator, while in December it is $23\frac{1}{2}°$ south of the equator. The sun, therefore, appears to migrate regularly north and south of the equator, producing our seasons. It alters the position of the north and south winds, for these do not blow towards the terrestial equator, but towards the "heat equator"—that is, towards that part which lies directly under the sun at that time of the year. Hence the **"trade winds,"** as they are called, migrate north and south of the equator, and one place may at one time be experiencing a north wind, while at a later time there will be a south wind there. Owing to the revolution of the earth these north and south winds appear as north-east and south-east winds. Why are they good for trade?

On the heat equator the hot air is going upwards—that is, there is no appreciable wind. Sailors call that region the "Doldrums." Suppose in olden times a sailing ship found itself in the doldrums, what would the sailors have to do in order to complete the journey?

5. In the centre of Asia there is a large mass of land which, owing to its small specific heat, rises rapidly in temperature during the summer and cools rapidly as the winter comes on. There are thus great extremes of heat and cold. In summer the heated land gives rise to convection currents in the air. Cool air rushes in on all sides, more especially from the sea borders to the south-west, south, south-east and east. These are

moisture-laden winds and are known as **monsoons or seasonal winds.** The south-west monsoon of India produces the heavy rainfall of 254 in. on the Ghats and 493 in. at Cherrapungi in Assam.

The north-east or winter monsoon is a dry wind. As soon as it arrives the ground becomes parched, rivers and lakes appear to dwindle and even in many cases to dry up, the grass withers, the trees turn brown, and birds and insects cease to sing or hum.

The change of the seasons is heralded by tremendous thunderstorms lasting several days. The downpour of rain is enormous and within twenty-four hours the ground is showing its green clothing, the birds are singing, insects humming, and all life, whether animal or vegetable, is awakened as if from a season's sleep.

All this is the result of the difference between the specific heats of land and water—of a solid and a liquid.

Questions and Problems—XVIII.

1. Explain why railway foot-warmers are made of copper and filled with hot water. Why is water the best substance to use apart from its cheapness?

2. Explain what is meant by the sentence that: "An insular climate is much more equable than a continental climate."

3. Some people warm their beds by placing in them a brick heated in the oven and wrapped in flannel. Compare this method with that commonly used of putting a hot-water bottle in the bed.

4. Which will cool the faster, the last cup of tea poured from the teapot or the empty teapot? Give reasons for your answer.

5. Can you give any reasons why July is hotter than June though Midsummer Day is on the 21st of June?

6. During the summer months the average difference between the temperature of day and night is 13° F. in the west of England, while it is 30° F. in Madrid. How do you account for this difference?

7. When using a bunsen ice calorimeter it is sometimes advised that water should first be placed in the tube and then the hot substance added. What are the advantages of this method?

8. Equal quantities of hydrochloric acid and sodium sulphate (Glauber's salt) are mixed together. Why is the temperature of the mixture very much below that of either of the constituents?

9. A hot-water bottle is filled with 4 litres (4000 c.c.) of water at 80° C. and is placed in a bed at 15° C. What quantity of heat is transferred from the bottle to the bed?

10. A brick weighing 3000 gm. is used to heat a bed. It is raised to 180° C. and put into the bed, the temperature of which is 15° C. What quantity of heat is transferred? The specific heat of the brick may be taken as ·21.

11. The specific heat of water and the latent heat of steam are very high compared with the corresponding values for other substances. Discuss the importance of these facts in connection with the use of water for heating a room.

*12. Describe exactly how you would find the specific heat of a substance such as a diamond.

13. A pound of ice and a pound of salt cooled to 0° C. are mixed together. How do you account for the considerable fall in temperature?

14. Compare the amounts of heat introduced into a room when equal weights of air and water at 100° C. are brought and allowed to cool to 15° C. The specific heat of air at constant pressure is ·237.

15. How many grams of air (specific heat = ·237 at constant pressure) will be warmed 10° C. by the heat given out by 10 kgm. of water when cooling from 70° C. to 15° C.?

16. The specific heat of water is thirty times as great as the specific heat of mercury. Is this any reason why water should not be used for filling thermometers?

17. What advantages are there in using thin copper for making calorimeters? Why are such calorimeters better than glass ones?

18. Six metal balls made respectively of (1) tin, (2) lead, (3) zinc, (4) copper, (5) iron, (6) aluminium, are heated to 200° C. and then quickly placed on a cake of wax. Discuss the result under the following conditions—

(*a*) The wax is (1) thin, (2) thick.

(*b*) The balls are all of the same (1) weight, (2) volume. State distinctly what part (1) conductivity, (2) specific heat plays in the experiment.

19. Write a short essay on the importance of water in the economy of nature from a thermal point of view.

20. State and explain the influence of a large fresh-water lake upon the climate of the district.

21. Show how the heating of a large building such as a school depends upon specific heat.

22. The average summer and winter temperatures of Lisbon are 50° F. and 70° F., while those of Múrcia are 49° F. and 79° F. What is the cause of the difference?

SECTION VIII*

RADIANT HEAT

148. Radiation.—In earlier chapters we have discussed two ways in which heat may be conveyed away from a hot body to colder bodies around it. Suppose we make an iron ball red hot and suspend it in the air, or hang up a bar of iron with one end red hot, which will do equally well. It gradually cools down. Let us try and see how the heat is lost.

1. Some heat is lost by conduction through the support.

2. Some is lost by convection. Throw a bright light on a screen in front of which is the red-hot iron. The air above the iron will be seen to be in motion, while that below it appears at rest. Burn some brown paper near the hot iron and note the direction of the convection currents. Is there a convection current below the iron? If so, in which direction is the air moving? In which direction is the heat passing from the hot iron?

3. Place your hand below the hot mass; does it feel hot? If so, this heat cannot have reached the hand either (*a*) by convection, for the hot convection currents are moving away from the hand, or (*b*) by conduction, for air is a bad conductor. There must be a third way in which heat is conveyed. It is called "Radiation," for, as we shall see, the heat is transferred in rays (or as waves) just as light is.

When heat is conveyed from place to place either by conduction or convection, it requires the presence of particles of matter. When heat is handed from one

particle to the next we call it conduction. It is called convection when the hot particles themselves move and carry off the heat with them. When heat is conducted along the iron poker you cannot see the particles of iron move. When heat is transmitted from the poker by conduction to the air near it, the air is seen to move and the heat is carried through the air by convection currents. The movements of the air particles can be easily seen.

149. Heat from the Sun.—Heat reaches us directly from the sun. To understand how it travels across the 93,000,000 miles of intervening space we must either imagine it filled with a conducting fluid or else that heat such as we receive from the sun can be transmitted through a vacuum. The latter seems to be the more probable. We therefore consider that the heat which spreads downwards from the red-hot iron and the heat that reaches us from the sun is radiant heat—that is, heat that reaches us by radiation.

150. The Chief Characteristics of Radiant Heat.—Occasionally there is an eclipse of the sun. The moon passes between the earth and the sun so that the sun's light and heat are cut off from us. Now it is found by the use of very delicate instruments that the light and heat from the sun are cut off at exactly the same time. What does this show with regard to the rate at which they travel from the sun to the earth?

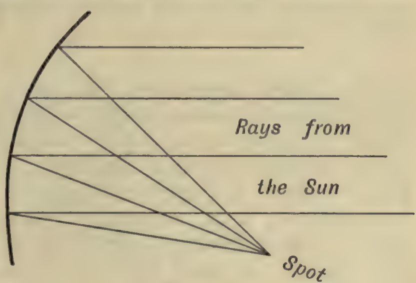


Fig. 90.

Radiant heat and light seem to be alike in several other particulars. Get a concave mirror and, holding

it in a beam of sunlight, obtain a bright spot reflected on to a piece of paper. Now pass the bulb of a thermometer through the bright spot. Is the spot hotter than the surrounding parts? If so, then radiant heat must have been reflected by the mirror in the same way as light is and according to the same laws.

Obtain a lens or magnifying glass, and repeat the previous experiment, using the lens instead of the mirror. Is radiant heat refracted, *i. e.* bent in passing through the glass lens, just as light is?

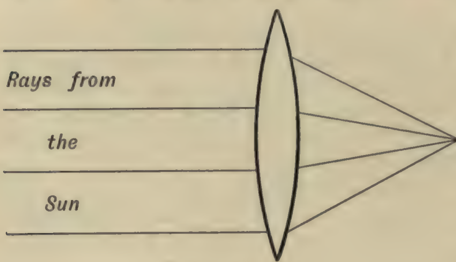


FIG. 91.

These results show that radiant heat and light obey the same laws of reflection and refraction.

Devise an experiment to find out whether radiant heat, like light, travels in straight lines. Perhaps you can suggest some everyday occurrences which will answer the question; if so note them down.

151. *Other experiments to show that radiant heat obeys the same laws as light.*—Everyone knows that in order to obtain a record of light rays a photographic plate or some surface sensitive to light is necessary. Just as there is paper sensitive to light, so can paper sensitive to heat be made. Several substances are known which change colour on heating. Any one of these might be used to make paper sensitive to heat. The iodide and chloride of cobalt are two such substances. Make a solution of one of these (say cobalt chloride), put in it one or two sheets of white paper or white blotting paper, and dry them very slowly. When dry the paper will be slightly pink. Hold a sheet near a bunsen burner. What happens? Let the paper

cool and notice that the original colour returns. It will do this more quickly if you breathe on it or supply moisture.

EXPERIMENTS 1 AND 2.

To show that radiant heat or heat rays travel in straight lines.

Pin a piece of sensitive paper to a board. Using a piece of wire gauze, fire clay, or asbestos, heated by a bunsen, as a source of heat rays, see whether you can get "shadows" as is possible with light. See diagram.

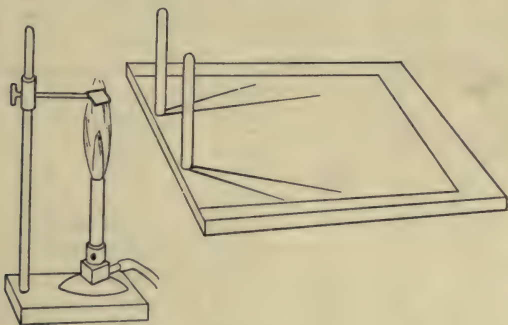


FIG. 92.

Make a hole in a sheet of tinfoil. Use the same source of heat rays on one side of the hole and notice what happens to sensitive paper held at different distances on the other side. Deduce all you can from your observations.

EXPERIMENT 3.

To show reflection of heat rays.

Obtain if possible two large concave metal mirrors, and place them a foot or so apart with the concave surfaces facing each other. At the focus of one place an iron ball heated red hot by means of a bunsen. At the focus of the other place a small piece of sensitive paper. Give reasons for what happens.

Experiment 4.

To show refraction of heat rays.

Find the focus of a convex lens or burning glass using the sun's rays. Note the position of the focus. Now interpose between the sun and the lens a piece of darkened or ruby glass to cut off most of the light, and place at the position of the light focus a piece of sensitive paper. Explain result.

152. The Detection of Radiant Heat.—A simple instrument to use in experiments with radiant heat is Leslie's Differential Thermoscope. Such an instrument can readily be constructed of two small, well-corked flasks, A, fitted with right-angled tubes as in the diagram. Two of these tubes are connected by rubber tubing with a U-tube containing coloured water. The other angled tubes, B, are fitted with rubber ends and solid glass stoppers. Their purpose is to equalise the pressures in A, A (and the levels in C), for on opening both ends B the air in the flasks is brought to atmospheric pressure.

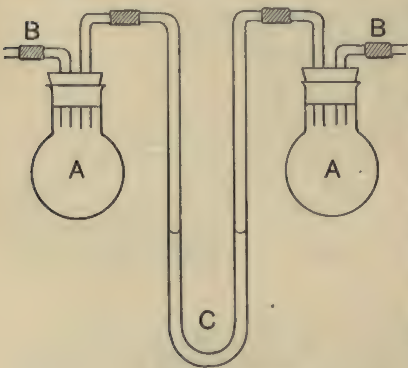


Fig. 93.

If either of the small flasks be heated, or cooled, then the pressures on either side of the U-tube C are unequal. The greater the difference of temperature the greater will be the difference of pressure. This difference can be measured by the difference between the heights of the columns of the coloured liquid.

Most text-books on heat recommend that the bulbs of the thermoscope should be coated with dead-black paint. What advantages are there in doing so? This point we will proceed to investigate in the next few paragraphs.

153. *Does heat more readily pass through a dead-black surface than through a polished surface?*—Obtain two metal vessels identical in all respects except that the outside of one is polished while that of the other is painted a dead black. Into each place equal quantities of hot water at the same temperature. Place the vessels so that they are to all appearances cooling under similar conditions and take the temperature of each at intervals of a minute. Keep them well stirred. Construct graphs of the fall in temperature. Do they both cool at the same rate? If not, which cools the faster?

Now reverse the experiment, filling the vessels with equal quantities of cold water, and placing them so that they are to all appearances receiving the same quantity of heat from a bunsen or electrical hot plate. The following may suit: Spread an even layer of sand over a sheet of tin about 10 in. long by 8 in. wide. Mount this on a suitable stand and put the bunsen as nearly as possible under the centre; suspend the two vessels at points equidistant from the centre, taking care that they do not touch the sand. Note the rise in temperature each minute. Which one absorbs the heat most quickly?

We thus see that the rate at which radiant heat is given out or taken in depends upon the surface. It does not depend upon the nature of the material. Similar sized vessels of iron, copper and nickel cool at the same rate if nickel plated and polished so as to make them externally alike. So also do they if each is covered with dead-black paint. A dead-black surface both radiates heat and absorbs it much more quickly than a polished surface.

154. A Good Radiator is a Good Absorber of Heat.—Try the following experiment. Obtain a piece of thin platinum and on it mark some simple design in ink. Allow it to dry. We have a black design on a polished background. The platinum is bright because it reflects the light; the ink is dark because the light is not reflected but absorbed. They act similarly with respect to heat. Make the platinum red hot; the design now appears brighter than the background. The ink which is a good absorber of heat and light when cold shows itself as a good radiator when hot.

155. Radiant Heat and Calorimetry.—In many experiments when measuring heat with a calorimeter much time is taken in the performance of the experiment, and during the whole of that time heat is being lost by radiation from the calorimeter if the temperature of the latter be above that of the surrounding atmosphere, or heat is being gained by absorbing the radiations of surrounding objects if the temperature of the calorimeter is lower than that of the objects around it.

This idea has been well expressed by a French scientist named Prevost. He called it the **"theory of exchanges."** All bodies are constantly receiving heat radiated by bodies around and at the same time are themselves radiating heat more or less quickly. If they receive more than they lose then they rise in temperature.

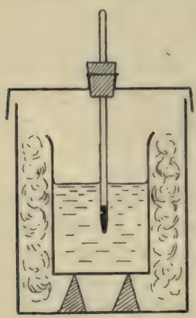


Fig. 94.

Such losses and gains should be made as small as possible when accurate experimental results have to be obtained. The calorimeter used should be specially arranged with this idea in view. Its outside should be well polished, for a polished surface is a bad radiator. The calorimeter should be enclosed in a metal case, the inner surface of which is polished;

a polished surface is a good reflector, and such heat as may be radiated from the calorimeter will then be reflected back again.

The calorimeter and its case should not be in contact, for the heat will be conveyed away by conduction. The calorimeter may be hung inside the case by badly conducting threads or it may rest on badly conducting supports such as cork or wool.

Convection currents between the calorimeter and the case should be prevented either by a cover or by a loose packing of wool.

Constructed in this way the calorimeter is capable of giving good results in the hands of a careful experimenter.

Another method of getting rid of errors due to radiation is often employed, as, for instance, in determining the (latent) heat of fusion of ice. By this method the experiment is commenced at a temperature as much above that of the surrounding air as it will be below it when the experiment finishes. For instance, if ice is being added to water when the temperature of the room is 15° C., start with water at 20° C. and add ice till it is cooled to 10° C. For the first half of the experiment more heat is being radiated from the calorimeter than is being received by it. During the latter part of the experiment it is receiving more heat than it is radiating. Finally the losses and gains will counterbalance each other.

How would you arrange an experiment when proposing to find the (latent) heat of vaporisation of water?

Questions and Problems—XIX.

1. Explain how it is that holding a book in front of you prevents your face from being scorched by the fire.
2. Why is it cooler in the shade than in the sunlight?
3. Why are the hot-water pipes painted dead black?
4. Why does the cook keep the kitchen kettle black while that intended for the table is well polished?
5. Is there any advantage to be gained by keeping the fire irons well polished?

6. Why are the helmets used by firemen always well polished?

7. Light and radiant heat travel at the rate of 186,400 miles per second. How long will it take a light wave to pass—

(*a*) from the moon to the earth, 238,840 miles,
(*b*) from the sun to the earth, 92,900,000 miles?

8. Two metal plates, one blackened the other polished, are hung in bright sunlight. Which will be at the higher temperature after a few minutes? Why?

156. Light and Radiant Heat Compared.—The results of §§ 153–4 can best be understood when we further consider the similarity between light and heat. If a beam of light is incident upon a polished surface most of it is reflected back again but some of it is absorbed. If the beam is incident upon the still surface of water some of the light is reflected, some is absorbed, and some is transmitted. So it is with radiant heat. Some things are good reflectors, some are good absorbers and some transmit the heat through them.

All this seems to show that light and heat are so very similar that they may be taken to be but forms of one and the same thing.

157. Differences between Light and Heat.—Some substances are transparent to light and some are opaque. Are such substances "transparent" or "opaque" also to radiant heat?

A glass screen is often placed before the fire as a fire screen. What is its effect? The glass is transparent to light: will it allow the heat to pass through it? If not, what happens to the heat? If it is absorbed the glass will get hot; does it do so? If it is not absorbed then the heat will be reflected. Does glass absorb, transmit, or reflect the heat? Hence we see that a body transparent to light will not necessarily allow heat to pass through it. If we retain the words transparent and opaque for use with regard to light, we require others to use with regard to heat.

A body which permits heat to pass through it is said to be "diathermanous." If it will not permit the heat to pass it is called "athermanous."

158. DIATHERMANCY.—Fit up a Leslie thermoscope with one bulb protected, till required, by being covered with a metal vessel. Arrange a lantern so that a strong beam of light and heat is directed upon the protected bulb. An arc lamp is best, but the lenses must all be removed, for, as we have seen when discussing the fire screen, glass is athermanous.

Expose the bulb for one minute to the beam of light and note the difference between the two water levels. Cover the thermoscope till the levels are equal again.

Now place a sheet of iron in between the exposed bulb and the lantern. Do the water levels change in one minute? What does this show you with regard to iron?

Repeat this, using a thin glass vessel filled with (*a*) water, (*b*) a solution of iodine in carbon disulphide, (*c*) a solution of alum.

Note in each case whether the intervening substance is (1) transparent or opaque, (2) diathermanous or athermanous.

159. SELECTIVE ABSORPTION.—White light, which we are accustomed to call colourless, can be shown to be composed of many different colours—the colours of the rainbow. When white light is incident upon certain substances, some colours are absorbed, some reflected, and the remainder transmitted.

A certain piece of glass allows only blue light to be transmitted through it; we therefore call the glass blue. On a plain piece of glass fasten some gold leaf. Light, when reflected from the surface of the latter, is found to be yellow—the colour of gold. On allowing light to pass through it we find that the transmitted light is green. The gold leaf has selected a certain colour for reflection, another for transmission and has absorbed the rest.

In a similar way bodies diathermanous to heat select certain rays for absorption, certain others for transmission and still others for reflection. For instance, lampblack absorbs all the heat rays received, reflecting none of them. Glass reflects some, absorbs some and transmits others. We have no natural sense, however, as we have in the case of light, which will enable us to differentiate these rays.

The behaviour of glass, however, teaches us a little about this selective absorption. On a clear morning, when the sun is shining through the window, note how hot are the sun's rays. The window remains cold though the rays from the sun have passed through it and have warmed the room inside.

Glass transmits the rays from hot bodies such as the sun, but absorbs those from relatively cooler bodies such as an ordinary room fire.

160. DIATHERMANCY IN NATURE. — Let us collect together the results we have obtained and note the influence of diathermancy on natural phenomena.

(1) Iron is opaque and athermanous.
(2) Glass is transparent and partially diathermanous.
(3) Water is transparent and nearly athermanous.
(4) A solution of alum is transparent but somewhat athermanous.
(5) A solution of iodine in carbon disulphide is opaque to light but diathermanous to heat.

161. GLASS HOUSES.—Glass houses are used for forcing plants. The sun's radiant heat can pass through the glass but is absorbed by the objects inside, which then give out dark rays, *i. e.* heat without light, which cannot pass through glass, and so the inside is kept warm.

Glass fire screens keep off the heat of the fire, as we have already seen, for the fire is giving off low temperature heat rays.

162. Atmospheric Moisture.—Heat and light from the sun are readily transmitted through our atmosphere whether it is moist or dry. This heat is absorbed by the earth, which in its turn radiates heat back again. The heat is now dark heat, and air is diathermanous to it if dry, but not so if moist. Moist air absorbs dark heat, hence a moist atmosphere acts like a blanket, keeping the heat near the earth. Hence our country, with its moist atmosphere, is warmer than one further away from the sea. This also accounts for the great change in temperature between day and night on dry sandy plains and elevated tablelands.

163. Dew and Hoar Frost.—On autumn mornings one often sees a deposit of dew on objects outdoors, and its occurrence prompts at once these questions: Why does it appear on some objects and not on others? Why is it sometimes found on one side of the road but not on the other? Why is it sometimes changed to hoar frost?

Let us try and find an answer to these and other similar questions.

Dew is the moisture produced by the condensation of vapour in the air. The condensation is produced by the cooling of the air, and as the condensation takes place on some objects and not on others this cooling must be local—that is, taking place in one or more places but not in all. We have now to hunt out causes which will produce—

(1) A vapour laden atmosphere.
(2) A cooling of this atmosphere close to the ground.

If you refer back to the work already done on vaporisation you will see that the higher the temperature of the air the more vapour it will hold. Hence we shall expect a more copious fall of dew to follow a warm day than a cool one.

The cooling of the air so that it will deposit its moisture as dew on things near the ground can only take place by its coming into contact with objects which cool

more rapidly than it does itself and which, therefore, in their turn cool the air above them.

This cooling is by radiation. Good radiators will get colder than bad radiators and make the air above them cooler and so receive a greater deposit of dew. Name some outdoor objects which are good radiators?

The bad radiator must not be a good conductor, for if it does it takes up heat from bodies below it and consequently does not get so cold as it would if it were a bad conductor.

Much heat radiated into the air will be reflected back again on a cloudy night, for clouds are good reflectors. On cloudy nights, then, the good radiators will receive back the heat lost by radiation and will therefore not get so very cold. There will be little dew on a cloudy night.

If there is much wind on a night when the production of dew is possible, little dew will be formed, for the wind will so quickly change the air above the cooled objects that the air itself will not get very cold and will not condense its moisture.

If there is no wind at all it is almost as bad, for air is a bad conductor and only the air quite close to the ground will be cooled and therefore only a little moisture deposited.

We thus see that the chief conditions for the formation of a copious deposit of dew are—

(1) A warm day followed by
(2) A clear cloudless night
(3) With only a very slight breeze.
(4) The presence of good radiators which are not good conductors.

If the cooling is so great that the temperature of the air is brought below freezing point, then the dew is deposited as hoar frost.

Questions and Problems—XX.

1. Why does the condenser lens of a magic lantern get hot while the objectives do not do so?

2. Explain why it is that a photographic studio gets so hot on a sunny day.

3. Gases, even when hot, are not good radiators; how is their radiating power increased in the gas stove used for warming a room?

4. Explain why fire bricks are used to surround the back of a fire grate even above the level of the hot coals.

5. Why does an incandescent Welsbach mantle make the room hotter than an ordinary gas flame does?

6. Why is dew more often found on grass and plants than on stones and metals?

7. Why does the temperature of the air in India fall very considerably during the dry season?

8. The inner ledge of the window is often hot in the sunlight while the window itself is cool. Explain why this is so.

9. A kettle is made so as to be fixed in front of a gas fire. If it is intended to boil water in it as quickly as possible, should the kettle be blackened or polished?

10. Grass fields in the country are frequently seen covered by a mist only one or two feet deep. How do you account for it? At what season of the year are you more likely to notice it? At what time of the day will it most probably occur?

11. Criticise the statement "the dew is falling."

12. Why does more dew form when the air is moving gently than when it is quite still?

13. Why does less dew form on a windy night than on a still night?

14. Dew forms almost always at night. Why does it not form during the day?

15. Under what conditions is a hoar frost formed instead of dew?

16. Why do we more often see dew on the lawns than on the paths around?

17. Archimedes is said to have set fire to the Roman fleet besieging Syracuse by means of "burning mirrors." Explain whether this is possible and, if so, how it could be done.

18. Are parts of railway engines polished for mere appearance or for any other reason? Explain your answer.

19. Franklin found that a dark piece of cloth placed on the snow in the sunlight sank deeper into the snow than a similar piece of light-coloured cloth. Why is this?

20. Why are white flannels used for cricketing suits?

21. What coloured clothes should a man wear if he has to spend his summer days indoors and out of the sunlight?

22. Why is it bad to wear black things in winter?

23. Why do snow and ice disappear more quickly if strewn with cinders?

24. Why do gardeners sometimes cover glass frames?

25. Why is a "Thermos" flask silvered?

SECTION IX*

HEAT AND WORK

164. THE STEAM ENGINE.—The history of the steam engine began two thousand years ago at Alexandria in Egypt, when Hero invented the *eolipyle.* Hero was a contemporary of the talented mathematician Archimedes, and lived about two hundred years before Christ. The principle of the eolipyle can be illustrated by making the apparatus in the figure out of glass tubing. When the apparatus is suspended as indicated and the water in the bulb made to boil by heating with a bunsen burner, the recoil of the escaping steam sets the eolipyle into rapid rotation. Hero's actual eolipyle was of the shape shown below. It is supposed to have been used by the priests for producing motion of apparatus in their temples. A century or two later the same idea was used in the construction of meat jacks.

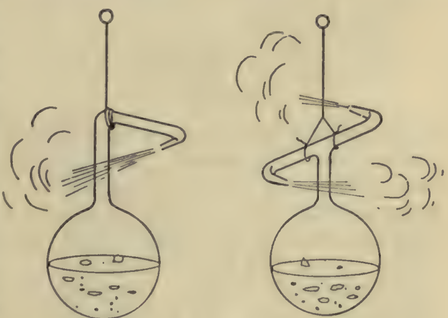


FIG. 95.

Since the time of Hero history records only one or two men in connection with the steam engine.

In the seventeenth century PAPIN in France caused a piston to move along a cylinder, using steam as the motive power. His cylinder was vertical and closed at the bottom (see Fig. 97). There was water at the bottom of the cylinder, and by alternately heating and cooling Papin was able to obtain an up-and-down motion of the piston. When the piston had reached the top of its course the furnace was taken away, the steam cooled and condensed, and in consequence of the atmospheric pressure the piston sank to its first position. If a weight W had to be lifted the pin P held up the piston until ready. The process was slow, but the same principle is still used in modern steam engines. It is said that Papin made a cylinder large enough to move a boat by paddle wheels.

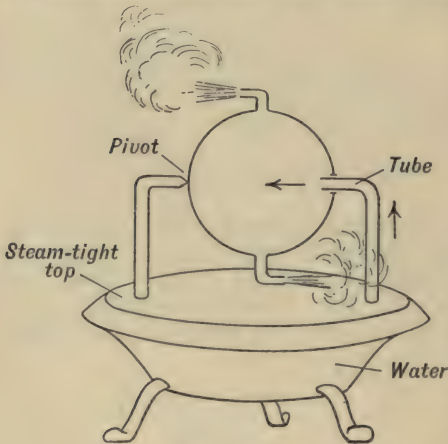


FIG. 96.

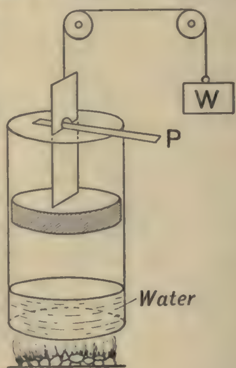


FIG. 97.

The next advance was a big one and was made at the beginning of the eighteenth century by THOMAS NEWCOMEN, a blacksmith of Dartmouth. The disadvantage of Papin's engine was that the whole of it—water, steam and cylinder—had to be cooled at each

stroke of the piston. Newcomen generated his steam in a separate compartment or boiler B (see Fig. 98) so that he could keep his steam always ready. To raise the piston the tap T was turned and steam admitted. At the top of the stroke T was closed and

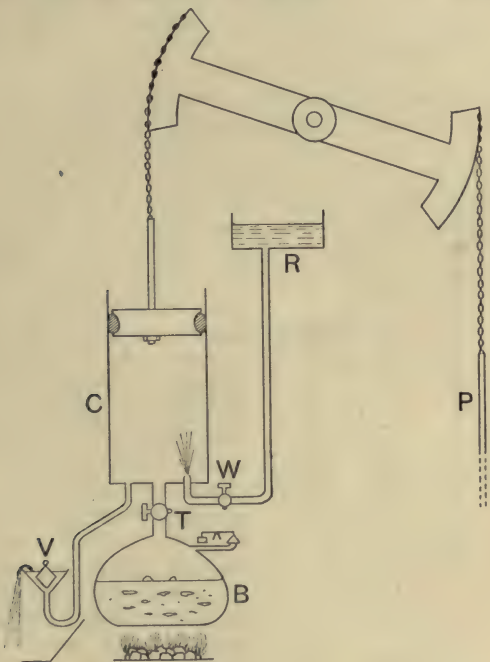


FIG. 98.

W opened, allowing a spray of water to enter from the tank R. This rapidly condensed the steam and the piston sank owing to atmospheric pressure. W was then closed and the process repeated. Condensed steam escaped from the valve V during the downstroke of the piston. Newcomen's engine was used successfully for pumping purposes. The motion of the piston was transmitted

to the pump rod P by means of a beam. His first engine was made in 1705. It is often known as an atmospheric engine. Can you say why it is so called?

An improved Newcomen engine was put up at Long Benton, near Newcastle-on-Tyne, in 1774, by JOHN SMEATON, a distinguished engineer of that time. In 1767 there were about fifty engines of the old type about Newcastle.

165. JAMES WATT.—The man who did most for the steam engine and who brought it up to a high standard of efficiency was James Watt. Every schoolboy has heard the story of James Watt and the kettle. He was a maker and mender of scientific instruments, and one day in the year 1763 he was asked to repair a model of Newcomen's engine which belonged to Glasgow University. Many deficiencies soon became evident and he set to work to devise improvements. He especially noted the large amount of steam required to raise the piston. On making measurements he found that four times the quantity necessary to fill the cylinder was required to push up the piston, owing to the large amount condensed during the first inrush. After many years of laborious work Newcomen's engine, remodelled and improved in every part, became Watt's engine.

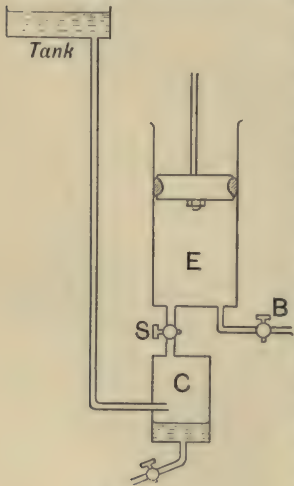


FIG. 99.

The main improvement introduced by Watt was that of the *condenser*. This was a closed vessel C, distinct from the cylinder but connected to it by means of a tube provided with a stopcock S (see Fig. 99). The idea of this was to prevent the walls of the cylinder

from getting cold. In Newcomen's engine a spray of water was used to condense the steam in the cylinder. This, of course, would also cool the cylinder walls and thus on the upstroke, when hot steam came into contact with them, much of it would condense and there would consequently be less power in the stroke. Watt's condenser C was connected to the cylinder E during the downstroke by means of the stopcock S, and cold water was injected into *it* instead of into the cylinder. On the upstroke, therefore, steam, entering from the boiler through B, found the walls of the cylinder hot, so that there was little or no condensation and all the steam entering was utilised in lifting the piston. This meant a very great saving of fuel, and Watt and Boulton (with whom he joined forces later) realised immense profits from this patent.

Another great improvement was his Double Acting Engine, the principle of which can at once be understood from the diagram (Fig. 100). The cylinder is closed at the top as well as at the bottom, and the steam from the boiler forces the piston on its downstroke as well as on the upstroke. On the downstroke the stopcocks 2 and 4 are open while 1 and 3 are closed. Steam enters 2 and forces the piston down. In addition, steam underneath the piston disappears into the condenser through 4, creating a partial vacuum and therefore making the downstroke more effective. On the upstroke 3 and 1 are open while 2 and 4 are closed. It is evident that Watt's Double Acting Engine was very much more powerful than the single acting cylinder.

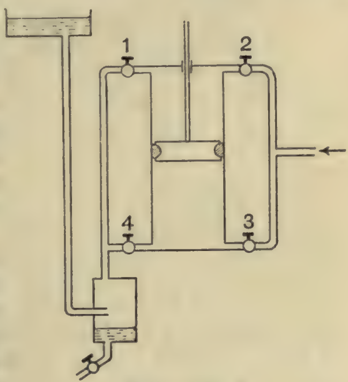


Fig. 100.

Watt economised his fuel still more by putting a steam jacket round the cylinder of his engine. This diminished more than ever the condensation of steam on entering from the boiler.

The above are only a few of the numerous devices invented by James Watt. Another familiar arrangement due to him is the "governor" to regulate the speed at which the steam engine works. The spindle SS is connected by cogwheels to the shaft which the piston rod drives. Two solid balls *mm* are fixed to arms hinged at *h*. The arms *aa* are not fixed to the spindle SS but to a concentric ring *r* which can slide up and down SS. As some of you may know, when the balls *mm* revolve a force is called into play called centrifugal force. Just as a weight at the end of a string which is being whirled round tries to fly off into space, so the weights *mm* will try to do the same. This will lift up *r*, and the faster the rotation becomes the higher will *r* rise. A lever fixed to *r* operates the valve which admits steam to the cylinder. When the engine goes too fast *r* rises and the valve admits less steam. If the engine slows down, *r* sinks and the lever opens the valve wider, allowing a greater inrush of steam to the cylinder.

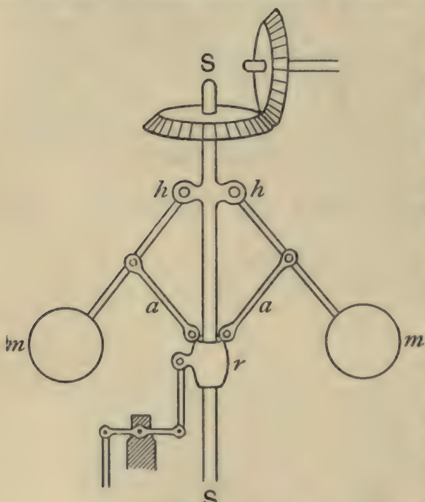


FIG. 101.

It might be mentioned here that the Glass Water

Gauge which is seen on practically all boilers of the present day was also the invention of Watt. (See Fig. 102.)

166. WORK.—Engines are machines for doing work, and we must now consider how work is measured. When a man pulls a pound weight from the ground to the roof of a building he does work. If the weight is doubled you will agree that the work is doubled. If the height of the roof is increased the work is increased in the same proportion. **Work is measured by multiplying the force acting, by the distance through which it acts,** *i. e.*

Work = Force × Distance.

In raising weights, the work done is equal to the product of the weight raised and the distance through which it is raised. Thus

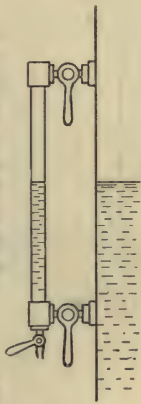


FIG. 102.

When	1 lb.	is raised	1 ft.,	the work done	is	*1 ft.-lb.*
,,	1 ton	,,	1 ft.	,,	,,	*1 ft.-ton*
,,	1 gm.	,,	1 cm.	,,	,,	*1 gm.-cm.*

If the force is acting vertically downwards it does not matter by what path the body is elevated. The work done will still be the product of the force into the vertical distance through which the body has moved. A man who carries 10 lb. up a hill 500 ft. high does 5000 foot-pounds of work whether he goes straight up the side of the hill or goes up by means of a very winding path.

The work done by a steam engine is measured by the force on the piston multiplied by the length of the stroke, *i. e.* the force multiplied by the distance through which the force acts.

Since work is the product of the force into the distance it might be represented by an area. If 5 lb. are

raised a distance of 75 ft. the work done will be equal to the area shaded |||||||| in Fig. 103. Suppose the force is constantly changing and at distances 0, 25, 50, 75 and 100 ft. it has values 2, 5, 8, 4 and 7 lb. respectively, then the work done will be the area shaded \\\\\\\\.

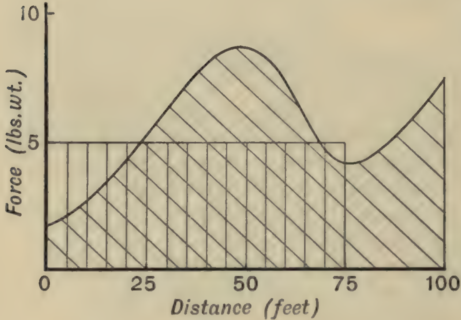


FIG. 103.

MATHEMATICAL EXERCISES—XXVI.

1. What is the amount of work done by a boy weighing 8 stone ascending a hill 1200 ft. high?

2. How much work is done in raising 14 lb. from the floor to the table 3 ft. above it?

3. Calculate the work done against gravity when a train weighing 150 tons travels to a station 50 miles away and at a height 75 ft. above the former station.

4. What is the work done against gravity when a mass of 20 kgm. is moved vertically 30 metres?

5. A well is bored 20 ft. deep and 9 sq. ft. in section. How much work was done in bringing up the soil to the surface? A cubic foot of soil weighs 200 lb.

6. How much work is done by a small boy weighing 44 lb. in going up a flight of steps 16 ft. high?

167. POWER.—**Power is the rate at which work is done—that is, the amount of work done in unit time.**

When 33,000 foot-pounds of work are done in one minute, then the rate at which work is being done is said to be one **horse-power.** In England this is the unit by means of which rates of work are compared.

In France a similar unit is used called the *Cheval-Vapeur,* and it represents the work done in raising 75 kgm. through 1 metre in each second.

1 horse-power = 550 ft.-lb. per sec.
1 cheval-vapeur = 542 ft.-lb. per sec.

Another unit of power, the **Watt,** is used in connection with electrical work—

$$1 \text{ watt} = \frac{1}{746} \text{ horse-power.}$$

168. The Steam Gauge.—It has been mentioned that the work done by a steam engine may be measured by the product of the force on the piston and the length of stroke. If we know also the number of strokes per minute we know the "horse-power" of the engine. But how can we measure the force on the piston?

James Watt did this with his *Mercury Steam Gauge,* which was really a U-tube, one limb of which was connected to the boiler by a small steam pipe. The pressure of the steam was balanced by a column of mercury in the other limb. In a barometer (see §§ 21, 22) the pressure of the atmosphere is balanced by a column of mercury of average height at sea level of 30 in. whatever the diameter of the tube. Now the pressure of the air on each square inch of surface is equal to a pressure of 15 lb., therefore a column of mercury 2 in. high represents a pressure of 1 lb. In Watt's steam gauge a difference of 2 in. in the heights of the mercury in the limbs of the U-tube meant a steam pressure of 1 lb. per square inch. Unfortunately, at high steam pressures this instrument becomes inconvenient.

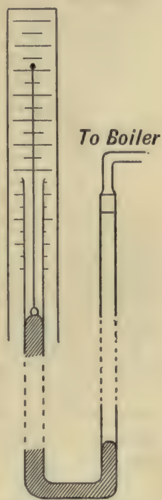


Fig. 104.

MATHEMATICAL EXERCISES—XXVII.

Suppose a steam engine has a piston with an area of 25 sq. in. and the length of its stroke is 16 in. The mean pressure on the piston as determined from the steam gauge is equal to 18 lb. per square inch and there are 84 strokes per minute. Of what horse-power is the engine, assuming that no work is expended in overcoming friction?

$$\text{Force pushing piston} = 25 \times 18 \text{ lb.}$$

If the length of each stroke is 16 in. (1·33 ft.) the work done

$$\begin{aligned} \text{per stroke} &= \text{Force} \times \text{Distance} \\ &= 25 \times 18 \times 1{\cdot}33 \text{ ft.-lb.} \end{aligned}$$

Therefore the work done per minute

$$= 25 \times 18 \times 1{\cdot}33 \times 84 \text{ ft.-lb.}$$

But 1 horse-power = 33,000 ft.-lb. per minute.

Therefore the horse-power of our engine

$$\begin{aligned} &= \frac{25 \times 18 \times 1{\cdot}33 \times 84}{33{,}000} \\ &= 1{\cdot}5 \text{ H.P. approximately.} \end{aligned}$$

1. Calculate the horse-power of an engine from the following—

Working pressure .	= 50 lb. per sq. inch.
Area of piston .	= 250 sq. in.
Length of stroke .	= 24 in.
No. of strokes .	= 500 per min.

2. What is the horse-power of a two-cylinder engine whose piston area is 90 sq. in. and stroke 16 in. if it works under an average pressure of 60 lb. per sq. inch and makes 450 strokes per min.?

3. Determine the I.H.P. (*i. e.* the indicated horse-power, or horse-power when the pressure is taken as that given by the steam indicator) of an engine with piston area 400 sq. in. and stroke 20 in. The steam indicator reads 55 lb. pressure and the number of strokes per minute was 480.

169. CONSERVATION OF ENERGY. — In early times philosophers occupied themselves with problems such as squaring the circle, preparing the elixir of life and in finding the philosopher's stone. Much time was spent in attempts at constructing a machine which would

go for ever, giving perpetual motion. All attempts at this problem failed, and it has now become clear that no work can be obtained from a machine or engine to which energy has not been first supplied. Energy is the power of doing work; anything that can be transformed into work is energy. It cannot be created, neither can it be destroyed. It exists under various disguises such as *heat*, *light*, in the *motion* of matter, *electricity*, and others. Sometimes one of these forms of energy apparently disappears, but in reality it is merely changing its disguise, and reappears as one or more of the other forms of energy.

In the early days of machines and engines the output of work was always thought to be less than the energy put into them. It was noticed, however, that heat was always produced. The experiments of Rumford and others have shown that heat is a form of energy, and when the heat energy produced by a machine is added to the *output* of work, it is found that the total energy is the same as that *put into* the machine. Thus we arrive at the **Law of the Conservation of Energy** which says that energy, like matter, is indestructible.

170. DIFFERENT FORMS OF ENERGY.—We have seen that to raise a weight requires the expenditure of mechanical energy or work. If we allow the weight to fall it regains its former position, and it appears at first sight that the energy put into it by raising it has disappeared. If the law of the conservation of energy holds, this cannot be the case. Then where has the energy gone?

Do the following experiments—

1. Arrange a pulley near the ceiling of the laboratory. Attach a piece of lead weighing about 500 gm. to a long thread and put the latter round the pulley. Immediately below the pulley place a thick piece of iron with the upper surface flat. Now take the temperature of the lead, then haul it up to the pulley and let it drop on to the iron. Repeat quickly more than a dozen times and again take the temperature. Explain the result.

2. Make a cardboard tube from a metre to a metre and

a half long of diameter 3 or 4 cm. Close the ends with corks. Cut a shallow depression in a large cork and pour in 40 or 50 gm. of fine lead shot. Note the temperature of the shots and put them into the tube. Hold the tube vertical and suddenly turn it through 180°. Repeat at intervals of a second, about 100 times. Then pour the shot quickly into the cork and take the temperature. Explain the result.

Why does a piece of lead get hot when hammered?

Mechanical energy may be converted into heat energy. Heat energy is converted back again into mechanical energy in the steam engine. When coal burns heat is given out. The coal contains chemical energy which in burning is changed into heat energy. Heat energy may again be converted into electrical energy and this again into light energy, and so on. **Energy is indestructible but it may be transmuted into different forms.**

Questions and Problems—XXI.

1. Do you do more work in ascending a flight of stairs quickly than in going up slowly?
2. Count Rumford in 1798 was superintending the boring of cannon for the Bavarian Government. He noticed the great amount of heat developed. What was the origin of this heat and upon what did its amount depend?
3. The British Government when buying coal require to know its "heat of combustion." Explain this term.
4. What is the source of heat produced in a pump when employed in pumping up a bicycle tyre?
5. A nail when hammered becomes hot. Where does the heat come from?
6. It is said that the sun is the source of the world's energy. Explain this statement.

171. Units.—We have considered a little how to measure the work done by a steam engine. The units used were practical ones such as *foot-pound* and *horse-power*. Before considering further the relations between the various forms of energy we must learn the scientific units in which work is measured.

The three fundamental units involved in all scientific measurements are those of *Length, Mass* and *Time.*

The **Unit of Length** is the **centimetre** and is the one-hundredth part of the distance between two marks on a platinum bar kept at Paris. The English unit of length is the **foot.**

The **Unit of Mass** is the **gram.** It is the mass of 1 cc. of pure water at a temperature of 4° C. The English unit of mass is the **pound.** (The "official" unit of mass in France is the **kilogram.** It is the amount of matter in a lump of platinum kept at Paris and is equal to 1000 gm.)

The **Unit of Time** is the **Second.** It is the $\frac{1}{3600}$ part of 1 hour, of which there are twenty-four in the "mean solar day."

All other units of measurement involve these three and are called **Derived Units.**

VELOCITY **is the rate at which a body changes its position.**—If a body is moving in a straight line so that in any second of time it changes its position by 10 cm. it is said to have a velocity of 10 cm. per second. When the same distance is passed over in the same time throughout its motion the velocity is said to be uniform.

The scientific **Unit of Velocity** is that of a body moving at the rate of **one centimetre per second.** The English unit of velocity is motion at the rate of **one foot per second.**

FORCE.—The velocity of a body can only be altered by the application of a force. When the velocity of a body is not uniform a force must be acting on it. **A force is that which changes or tends to change the state of rest or of uniform motion of a body.**

The scientific **Unit of Force** is called the **Dyne.** If a dyne acts on a mass of 1 gm. the velocity of the latter will increase 1 cm. per second, in every second during which the unit force acts. The dyne is very nearly equal to $\frac{1}{981}$ gm.

The English unit of force will be that force which, acting on 1 lb., increases its velocity by 1 ft. per second,

in each second the force acts. It is very nearly $\frac{1}{32}$ lb. and is called a **Poundal.**

ACCELERATION.—We have seen that a force is that which changes the velocity of a body. **The rate at which the velocity changes is called the acceleration,** *i.e.* the velocity added per second. If twice the force acted on a body, the velocity added in each second would be doubled. If the force were three times, the velocity added per second would be trebled; and so on. Therefore acceleration is proportional to the force acting.

Unit acceleration is produced when unit force acts on a body of unit mass. In other words, when 1 dyne acts on 1 gm. the velocity added in each second is 1 cm. per second.

If 1 dyne acted on $\frac{1}{2}$ gm. the acceleration would be doubled, *i. e.* the velocity added per second would be 2 cm. per second. If 1 dyne acted on $\frac{1}{3}$ gm. the velocity added per second would be 3 cm. per second, and so on. From this we see that the product of the mass into the acceleration is equal to the force.

$$1 \times 1 = \tfrac{1}{2} \times 2 = \tfrac{1}{3} \times 3 = \ldots\ldots = 1$$

Generally, then, we may write

$$F = m \times a$$

where F = force in dynes, m = mass in grams.
a = acceleration in cm. per sec. per second.

172. ACCELERATION DUE TO GRAVITY.—The law of universal gravitation declares that every piece of matter attracts every other piece of matter. This means that a stone near the surface of the earth is attracted by the earth and at the same time the stone is attracting the earth though to a smaller extent. Hence all things near the earth's surface fall towards the earth.

Suppose, then, that a person holds out a stone. The earth is exerting a *force* on this stone, and if the stone is released it will move towards the earth.

Now there are in ordinary language two sorts of forces—

(1) Impulsive forces, which act for a moment only and then cease. Such forces produce a constant velocity in the body acted upon. The body will go on moving at the same rate for ever unless another force opposes its motion.

(2) Constant forces, which are constantly adding on further velocities to the initial velocity produced. Such forces will produce a steadily increasing velocity. The gravitational force of the earth is of this kind.

When the stone is dropped it will gain a certain velocity during the first second; during the second second the velocity will be doubled, and so on. The gain in velocity is known as acceleration, and the acceleration produced is proportional to the force which produces it. That is to say, the greater the force the greater will be the velocity which is added on each second.

The force is also proportional to the mass of the body moved. This will be clear when you consider that the force which produces a certain acceleration on a body of large mass must be greater than one which produces the same acceleration on a body of much smaller mass.

Thus we see again that

$$F = m \cdot a$$

where F = the force acting on a body of mass m and producing an acceleration a. This is true of all constant forces, whether gravitational or otherwise.

Experiments show that all bodies, when allowed to fall freely, acquire the same acceleration. The velocity added in each second is slightly more than 981 cm. per second. Suppose the falling body has a mass of 5 gm., then the force in dynes which acts on it due to the earth's attraction is

$$F = m \cdot a = 5 \times 981 = 4905 \text{ dynes.}$$

The attraction of the earth on a body is, of course, the *weight* of the body. The acceleration due to the earth's attraction is denoted by g, and varies slightly

from place to place. We may, then, say that the weight of a body is

$$W = mg \text{ dynes.}$$

The force of gravity acting on 1 gm. = 981 dynes.
The force of gravity acting on 1 lb. = 32·2 poundals.

Mathematical Exercises—XXVIII.

1. With what force will a body of mass 24 gm. be attracted to the earth?
2. What would the force of attraction be if the mass of the body was 30 gm.?
3. A stone weighing 10 gm. is dropped from a height. With what force is it drawn towards the earth?
4. A force f acting on a mass of 10 lb. increases its velocity every second by 12 ft. a second; a second force F acting on a mass of 15 lb. increases its velocity every second by 7 ft. a second. Find the ratio of f to F.
5. What force will produce an acceleration of 10 cm. per sec. per sec. when acting upon a mass of 25 gm.?
6. What will the force be if the mass be 20 gm. and the acceleration produced be 15 cm. per sec. per sec.?
7. A force of 100 dynes acts upon a mass of 20 gm. What acceleration did it produce?
8. What acceleration is produced when a force of 120 dynes acts upon a mass of 15 gm.?
9. A force of 24 gm. weight acts upon a mass of 36 gm. What acceleration is produced?
10. What acceleration is produced when a force of 8 poundals acts upon a mass of 20 lb.?
11. A force of 10 lb. weight acts on a mass of 20 lb. What acceleration is produced?

173. Work.—Work is the product of the force acting into the distance through which it acts. **Unit work is done when unit force is overcome through unit distance.**

The scientific *unit of work* is done when a force of 1 dyne is overcome through a distance of 1 cm. It is called an **erg.** If a force of F dynes acts through a distance of d cm. the work done will be Fd ergs.

The English unit of work is the work done when a force of 1 poundal is overcome through a distance of 1 ft.

EXAMPLE.—*To find the number of ergs in a foot-pound.*

A foot-pound is the work done when a mass of 1 lb is raised vertically a distance of 1 ft.

1 lb. = 453·6 gm. 1 inch = 2·54 cm.

Force exerted by the earth on 1 gm. is

$$F = m \, . \, a = 1 \times 981 = 981 \text{ dynes.}$$

Force exerted on 1 lb. $= 453{\cdot}6 \times 981$ dynes.

1 foot-pound = work done when $453{\cdot}6 \times 981$ dynes act through $2{\cdot}54 \times 12$ cm.
$= 453{\cdot}6 \times 981 \times 2{\cdot}54 \times 12$ ergs
$= 13{,}400{,}000$ ergs, which may be written shortly,
$= 1{\cdot}34 \times 10^7$ ergs.

174. *The relation between mechanical energy and heat energy.*—We have already mentioned that energy is indestructible and that it can be changed from one form to another.

In order to get some idea of the amount of energy in the form of heat that can be obtained from mechanical energy, do the following experiment.

Obtain a strong cardboard tube about 5 or 6 cm. in diameter and from a metre to one and a half metres long. Fit corks tightly into the ends. Cut a depression in the top of a large cork sufficient to hold 200 or 300 gm. of small lead shot. Take the temperature of the lead shot, put them into the tube and fix the corks tightly.

Hold the tube vertically and quickly rotate it through 180°. Hold it in this position for about 1 second and then quickly invert again. After another interval of 1 second, repeat. Do this 100 times and then quickly pour the shot into the depression in the large cork and take their temperature.

When the tube is turned work is done on the shot by raising them the length of the cardboard tube against the earth's gravitation. When the shot fall to their original position this work is transmuted into heat.

The tube is again turned, the shot fall, and the work done on them is again changed into heat energy which raises the temperature of the shot.

The mechanical work supplied can be calculated from the mass of the shot, the distance they fall, and the number of times they fall.

The heat produced may be measured if we know the mass of the shot, their specific heat, and the rise in temperature.

Mechanical energy, i. e. the amount of work done.

Let h = distance between the centre of the shot at one end and the centre of the shot when they reach other end of the cardboard tube.

Let m = mass of shot.
,, g = acceleration due to gravity.

Then the force exerted on the shot by the earth is

$$F = m \cdot g \text{ dynes.}$$

This acts through a distance h, therefore at each turn of the tube

$$\text{Work done} = F \times h = mgh \text{ ergs.}$$

Suppose the tube is turned N times.

$$\text{Then total work done} = Nmgh \text{ ergs.}$$

Heat energy, i. e. the quantity of heat produced.

Let the initial temperature of the shot = $t°$ C.
,, final ,, ,, = T° C.

Then if S = specific heat of lead shot, the heat produced is $m \cdot S \cdot (T-t)$ calories.

We can now say that
$mS \cdot (T-t)$ units of heat have been produced by $Nmgh$ ergs of work.

1 unit of heat will be produced by $\dfrac{Nmgh}{mS \cdot (T-t)}$ ergs of work

$$= \frac{Ngh}{S(T-t)} \text{ ergs.}$$

You will observe that to get this result the mass of the shot need not be known.

The amount of mechanical energy which is necessary to produce one unit of heat is called the **Mechanical Equivalent of Heat** and is usually denoted by J.

175. *The determination of the mechanical equivalent of heat.*—The amount of work that has to be done in order to produce unit quantity of heat was first experimentally determined by Dr. Joule of Manchester (whence the letter J). Other men were thinking about the transformation of energy at the same time and one had even obtained the correct value for the mechanical equivalent on theoretical assumptions. Joule's method was to transform by means of friction a definite

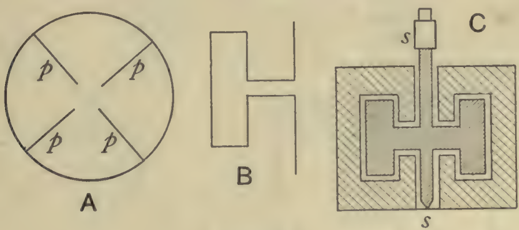


FIG. 105.

quantity of mechanical work into heat and to measure the quantity of heat produced. As the apparatus was rather complicated only the main principles of the experiment will be given here.

Let us suppose that a metal vessel or calorimeter is divided up by four partitions p, p, p, p, as shown in plan at A (Fig. 105). Each partition is cut out in such a way as to allow metal vanes of the shape B to just slip through it. The shape of the vanes does not matter at all so long as they pass through similarly shaped holes in the partitions p, p, p, p. C shows more clearly what is meant and represents a section through two of the partitions of the calorimeter with vanes in position just passing through. The vanes can be rapidly rotated about the spindle SS.

An idea of Joule's experiment may now be obtained by considering Fig. 106. The calorimeter containing its partitions and vanes is represented by H. During an experiment it contains water, the temperature of which is read on the thermometer *t*. By releasing a weight *m*, which is connected by a thread over the pulley P to the spindle, the vanes can be made to rotate. The distance through which the weight has fallen is measured on the scale M. As the vanes rotate they

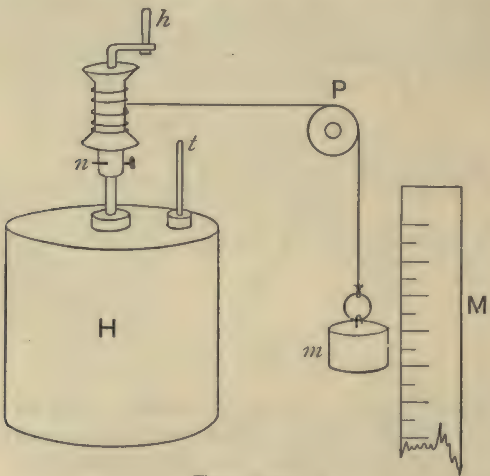


FIG. 106.

set the water in motion. The moving water is pulled up suddenly at each partition and its energy of motion is converted into heat energy which, being given to the calorimeter and its contents, causes a rise in temperature. One fall of the weight *m* may not be sufficient to give an appreciable rise on the thermometer *t*, therefore the pin *n* may be taken out and *m* wound up by means of *h* without disturbing the vanes. After replacing the pin *n*, *m* is allowed to fall a second time, and so on.

Let us see how much work has been done.

We have seen that work is measured by taking the product of the force acting, into the distance through which it acts. The force in this case is the attraction of the earth on *m*, and we will suppose *m* falls a distance *d* cm.

$$\text{Force} = m \, . \, g \text{ dynes.}$$
$$\therefore \text{Work done in each fall} = m \, . \, g \, . \, d \text{ ergs.}$$

If the weight falls *n* times the total work done is $n \, . \, m \, . \, g \, . \, d$ ergs.

Now let us see how much heat has been produced.

The things heated are the calorimeter and its contents. Let the "water equivalent" (see §§ 136–8) of the calorimeter and its contents be S—that is, the quantity of water which requires the same amount of heat to raise its temperature 1° C. as does the calorimeter and its contents. Suppose the rise in temperature in an experiment was $t°$ C. Then the heat produced will be the same as that required to raise S gm. of water through $t°$ C., *i. e.* $S \, . \, t$ calories.

Hence we have

$S \, . \, t$ calories are the result of $n \, . \, m \, . \, g \, . \, d$ ergs of work.

1 calorie is produced by $\frac{nmgd}{St}$ ergs of work.

This will be J—the Mechanical Equivalent of Heat.

After making careful allowances for many sources of error, including the work expended in overcoming the friction of the pulleys, Joule obtained a value for J of $42{\cdot}67 \times 10^6$ ergs.

Joule's experiments have been repeated and other methods for finding J have been devised. **They all agree that to obtain one unit of heat (gram-calorie) 42 million ergs of work must be done.**

176. The First Law of Thermodynamics. — The results of these experiments lead us to what is known as the First Law of Thermodynamics, which may be expressed thus—

When work is transformed into heat, or heat into

work, the quantity of work is mechanically equivalent to the quantity of heat. We may put it

$$W = J \, . \, H \text{ where } J \text{ is Joule's equivalent.}$$

This law is really an expression of the principle of the Conservation of Energy applied to two forms of energy—heat and work.

J is sometimes expressed in units other than the *c.g.s.* (centimetre-gram-second) system, and as some of these are important we give them here.

$$\text{Since } W = J \, . \, H$$

$$\therefore J = \frac{W}{H}$$

Taking for our

Unit of Work	Erg. (dyne-cm.)	Gram-centimetre	Foot-pound	Foot-pound
Unit of Heat	Gram-degree (calorie)	Gram-degree (calorie)	Pound-degree (0° C. to 1° C.	Pound-degree (32° F. to 33° F.)
Then J =	42×10^6	42,600	1390	772
	1	2	3	4

We might express each set of units in this way—

1. If a weight of 1 dyne falls to the ground a distance of 42×10^6 cm., the heat developed would raise 1 gm. of water through 1° C.

2. If a weight of 1 gm. falls to the ground a distance of 42,600 centimetres, the heat developed would raise 1 gm. of water through 1° C.

3. If a pound of water falls to the ground a distance of 1390 ft., the heat developed would raise it through 1° C.

4. If a pound of water falls to the ground a distance of 772 ft., the heat developed would raise it through 1° F.

Mathematical Exercises—XXIX.

1. From what height must a piece of lead at 10° C. be dropped in order that it may be completely melted by the heat generated at the impact? (Specific heat of lead = ·032 cal.; latent heat = 5 cal.; melting point = 327° C.)

2. How much warmer should the water at the bottom of Niagara Falls be than at the top? (Height of falls = 160 ft.)

3. From what height must a hailstone (temp. 0° C.) fall so that the heat produced by impact with the ground may just melt it? (Latent heat of ice = 80.)

4. An engine works at 5 horse-power for 6 hours and half the work done is used in melting ice at 0° C. How many pounds of ice will be melted? (J = 1390.)

5. Sir Humphrey Davy melted two pieces of ice by rubbing them together at 0° C. How much work did he do when melting 20 gm. of ice?

6. The water of a certain waterfall falls 500 cm. What is the temperature at the bottom when that at the top is 8° C. assuming that no heat gained by falling is dissipated?

7. A steam engine has an indicated horse-power of 25. How many units of heat does it convert into useful work per minute?

ANSWERS TO MATHEMATICAL EXERCISES

§ 14. (*a*) 6·94 gm. per sq. cm. (*b*) ·3 gm. per sq. cm.

I.

1. ·00367 c.c. **2.** ·00329 c.c. **3.** ·00356 c.c.
4. ·00370 c.c. **5.** 1·289 gm. **6.** 1·257 gm.
7. 1164·6 gm. **8.** 1·290 gm.

§ 17. 343° abs. 243° abs. 583° abs.

II.

1. 1·10 litres. **2.** Vol. becomes 420 c.c.
3. 39° C. **4.** 81·9° C. **5.** 159° C.
6. (1) 1·247 gm. (2) 1·204 gm. (3) 1·164 gm. (4) 1·127 gm.
7. (1) 364·5 c.c. (2) 380·3 c.c. (3) 429·9 c.c. (4) 313·5 c.c.
8. 1·84 litres.

§ 23. Ht. of glycerine baro. = 321 in. (= 30 in. mercury).
Change in Ht. = 10·7 in.

III.

1. 1020 gm. per sq. cm. **2.** 14·5 lb. per sq. in.
3. 2125 lb. per sq. ft. **4.** (*a*) 302·7 in.; (*b*) 765·6 cm.
5. 34·56 ft. **6.** 866·1 cm. **7.** 77·2 cm.

IV.

1. (*a*) 70° C.; (*b*) 104° F. **2.** − 17·7° C.
3. (*a*) 8° R.; (*b*) − ·8° R.; (*c*) 48° R.
4. (*a*) 37·5° C.; (*b*) 75° C. **5.** − 28·8° C.
6. − 40° C. and F. **7.** ·26° F. or ·1° C.
8. 1·2° F. too low. **9.** 320° F.
10. (1) 36° F.; (2) 16° R. **11.** 968·4 ft.
12. 27115 ft.
13. (*a*) 14,042 ft.; (*b*) 4,261 ft.; (*c*) 11,814 ft.; (*d*) 16,269 ft.

V.

1. $5\cdot\dot{5}°$ C. **2.** (*a*) $17\cdot\dot{2}\dot{7}°$ C.; (*b*) $63\cdot\dot{0}\dot{9}°$ F.
3. (*a*) 172·76° F.; (*b*) − 202° F.
4. $43\cdot\dot{3}° - 32\cdot\dot{2}° = 11\cdot\dot{0}\dot{9}°$ C.
5. (*a*) 122° F. − 95° F. = 27° F.; (*b*) ·09° F.
6. Press. changes in ratio 288 : 293.
7. 1 mm. diff. = ·037° C. **8.** 50° F. and 59° F.

§ 40. 80 cm. 85 cm. 101 cm. 64 cm. 70 cm. 75 cm.

VI.

1. (1) 22·5 c.c.; (2) 11·25 c.c.; (3) 7·5 c.c.
2. 36 c. in. **3.** 31 in. **4.** 297·72 gm.
5. (*a*) 20 cm.; (*b*) 60 cm.
6. (*a*) 37·5 cm.; (*b*) 150 cm.; (*c*) 225 cm. above level in closed limb. **7.** (*a*) ·15 cm.; (*b*) 74·637 cm.

VII.

1. ·000047 c.c. **2.** ·00025 c.c. **3.** ·000148 c.c.
4. ·000378.

VIII.

1. ·00038 c.c. **2.** ·000153 c.c. **3.** 100·25 c.c.
4. (*a*) ·000155; (*b*) ·000025.

IX.

1. $\cdot 00\dot{1}\dot{5}$. **2.** ·00108. **3.** 70·63 c.c.
4. 74·9° C. **5.** 33·7 c.c. **6.** ·00105.
7. 4·50 gm. **8.** 13·356 gm.

X.

1. (*a*) ·00115; (*b*) ·001175. **2.** 94·41 gm. **3.** ·000425.

XI.

1. ·000012. **2.** ·000019. **3.** ·000017.
4. ·0000083. **5.** ·000023.

XII.

1. 1·7095 cm. **2.** ·066 in.
3. (1) 100·02835 cm.; (2) 100·0945 cm.; (3) 100·189 cm.
4. (*a*) 250·110 sq. cm.; (*b*) 250·330 sq. cm.
5. (*a*) 110·0596 cm.; (*b*) 82·0444 cm.; (*c*) 9029·768 sq. cm.
6. 14·16 c.c. **7.** 4·934. **8.** ·0000146.
9. ·0000128. **10.** 264·5° C. **11.** 127 cm.
12. 31·4 in. **13.** 24·086 cu. ft.

XIII.

1. ·0616 in. **2.** ·0396 in. per yd. **3.** 8·04536 c.c.
4. 74·76 cm. **5.** 250·5 c.c.
6. (*a*) 19·40 gm. per c.c.; (*b*) 19·34 gm. per c.c. **7.** 41·93 cm.

XIV.

1. 568 cal. **2.** 541 cal. **3.** 531 cal.

XV.

1. 1600 cal. **2.** 10,740 cal. **3.** 12,340 cal.
5. 2000 cal. **6.** 22·5° C. **7.** 6,370 cal.
8. The water reaches the b.p. and ·37 gm. are boiled away.

XVI.

1. 1611 cal. **2.** 762·5 cal.
3. (1) 2000 cal.; (2) 10,740 cal.
4. ·93 gm. **5.** mL cal.
6. (*a*) 540 cal.; (*b*) 527·8 cal.; (*c*) 529 cal.; (*d*) 528·6 cal.
7. 45·5° C. **8.** 44·6° C. **9.** 57·9° C.
10. (*a*) 2·47 gm.; (*b*) 5·07 gm. **11.** 282·14 gm.
12. $\frac{637x}{x+y}$. **13.** $\frac{637a + bC}{a+b}$.

XVII.

1. (*a*) 1·74 cm.; (*b*) 1·74 cm. **2.** 1·27 cm.
3. (*a*) 2·35 cm.; (*b*) 1·74 cm.; (*c*) ·91 cm.

XVIII.

1. (*a*) 35·42° F.; (*b*) 35·28° F.; (*c*) 34·2° F.; (*d*) 37·64° F.
2. 59·7° F. **3.** 11·05° C. or 51·89° F.
4. (*a*) ·85; (*b*) ·71; (*c*) ·66; (*d*) ·62; (*e*) ·73; (*f*) ·56.

XIX.

1. 78 per cent. **2.** ·68. **3.** 0° C.
4. (*a*) 62 per cent.; (*b*) 44 per cent.; (*c*) 43 per cent.; (*d*) 79 per cent.

XX.

1. (*a*) 73 per cent.; (*b*) 54 per cent.; (*c*) 100 per cent.; (*d*) 71 per cent.; (*e*) 51 per cent.
2. 12·8° C. or 55·1° F. **3.** ·52. **4.** 7·2° C. **5.** ·82.

XXI.

1. 2400 cal. **2.** 1650 cal. **3.** 14340 cal. **4.** 16·25° C.
5. (*a*) 80 cal.; (*b*) 80 cal.; (*c*) 80·6 cal.; (*d*) 80·9 cal.
6. 14·3° C. **7.** 7·5 gm. **8.** 45·78° C. **9.** 14·34 lb.
10. 90 cal. **11.** 21·3° C. **12.** 3600 cal. **13.** 21,510 cal.
14. 100 gm.

XXII.

1. ·107. **2.** 27·9 cal. **3.** 72° C.
4. 1636·8 cal. **5.** 412·5 cal. **6.** 154·38 gm.
7. ·0304. **8.** ·604. **9.** ·223.
10. 1670° C. **11.** 1236·9 cal. **12.** 1 : ·59.
13. ·437. **14.** ·56.

XXIII.

1. (*a*) 9·15 cal.; (*b*) 23·25 cal.; (*c*) 14·5 cal.; (*d*) 17·85 cal.; (*e*) 17·01 cal. **2.** 50·4 gm. **3.** 2·34 gm.
4. (*a*) 2·621 gm.; (*b*) 3·285 gm.; (*c*) 1·104 gm.; (*d*) 1·056 gm.

XXIV.

1. 6151·5 cal. **2.** 2200·8 cal. **3.** ·23 cal.
4. 131·6 gm. **5.** ·15 cal. **6.** ·099 cal.
7. ·1 cal. **8.** (*a*) 3·71 gm.; (*b*) 39 gm. **9.** 30° C.

XXV.

1. 6 : 5. **2.** ·0331 cal. **3.** 224·5 gm.
4. ·099 cal. **5.** ·093 cal. **6.** ·0321 cal.
7. 16·1 gm. **8.** ·222 cal.

QUESTIONS XVIII.

9. 260,000 cal. **10.** 103950 cal. **14.** 237 : 1000.
15. 232,067 gm.

XXVI.

1. 134,400 ft.-lb. **2.** 42 ft. lb.
3. 25,200,000 ft.-lb. or 1125 ft.-tons.
4. 60,000,000 gm. cm. or 600 kg. metres.
5. 360,000 ft.-lb. **6.** 704 ft.-lb.

XXVII.

1. 378·8 horse-power. **2.** 196·3 horse-power.
3. 533·3 horse-power.

XXVIII.

1. 23,544 dynes. **2.** 29,430 dynes. **3.** 9810 dynes.
4. 8 : 7. **5.** 250 dynes. **6.** 300 dynes.
7. 5 cm. per sec^2. **8.** 8 cm. per sec^2. **9.** 654 cm. per sec^2.
10. ·4 ft. per sec^2. **11.** 16·1 ft. per sec^2.

XXIX.

1. 6460 metres. **2.** ·21° F. **3.** 34,080 metres.
4. 267 lb. **5.** 671×10^8 ergs. **6.** 8·0117° C.
7. 1068·6 B.T.U.

INDEX

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